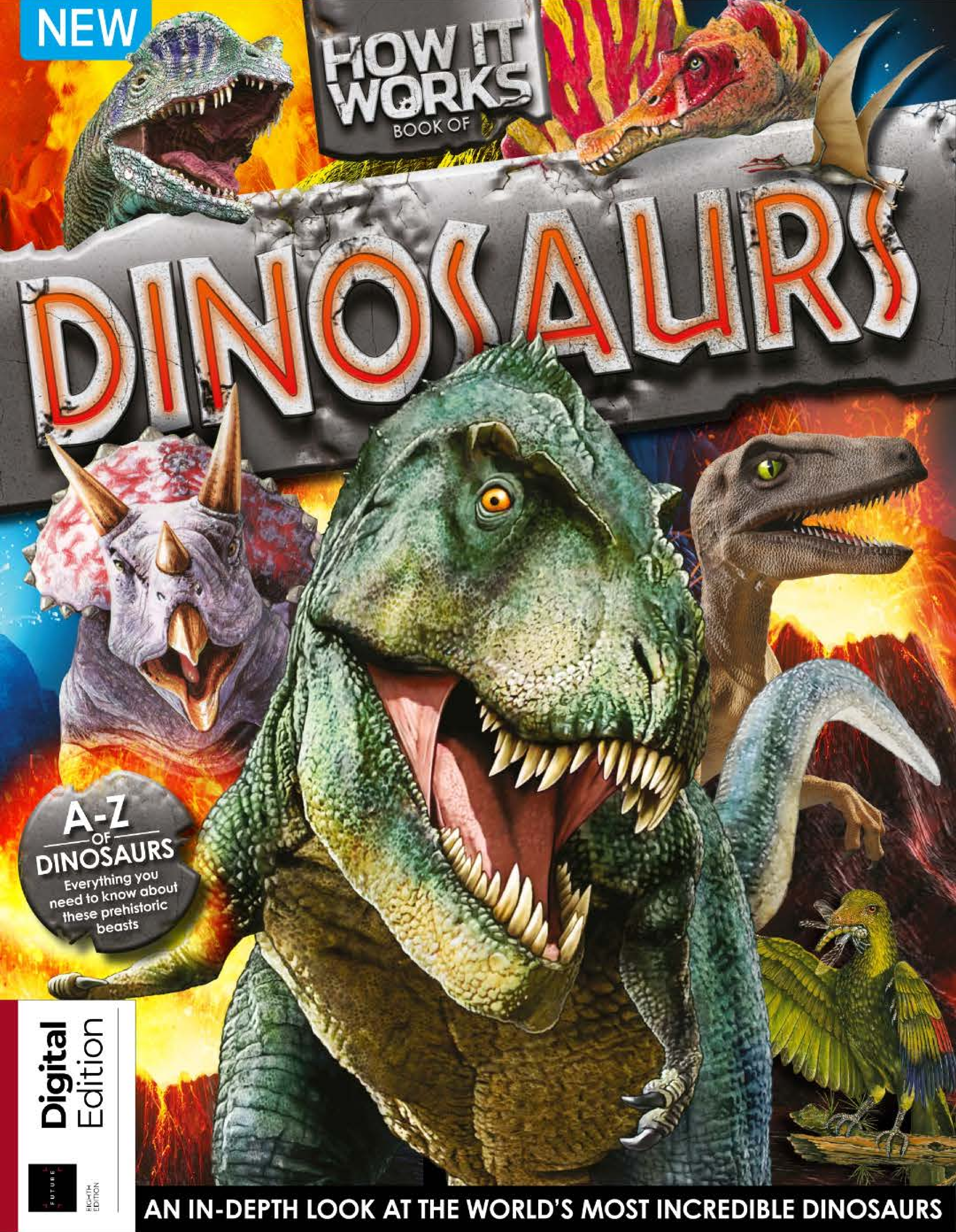

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HOW IT WORKS
BOOK OF
DINOSAURS
A-Z OF DINOSAURS
Everything you need to know about these prehistoric beasts
Digital Edition
FUTURE
EIGHTH EDITION
AN IN-DEPTH LOOK AT THE WORLD'S MOST INCREDIBLE DINOSAURS

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At first glance, dinosaurs seem like the product of a wild imagination – how could such weird and wonderful creatures ever have existed on our Earth? Before the extinction event that changed their world forever, dinosaurs and their reptilian relatives of the sea and sky ruled the prehistoric world. From Allosaurus to Zuniceratops, travel back in time to the age of the dinosaurs with the How It Works Book of Dinosaurs and discover these 'terrible lizards' for yourself. We've gathered together some of the most amazing creatures and got right under their skin so we can demonstrate to you how they worked. Did Velociraptors hunt in packs? Why did herbivores grow so massive? Find out how the dinosaurs survived and thrived, about the mass extinction event that ended it all, and what these ancient creatures left behind for us to find...

HOW IT WORKS BOOK OF

DINOSAURS

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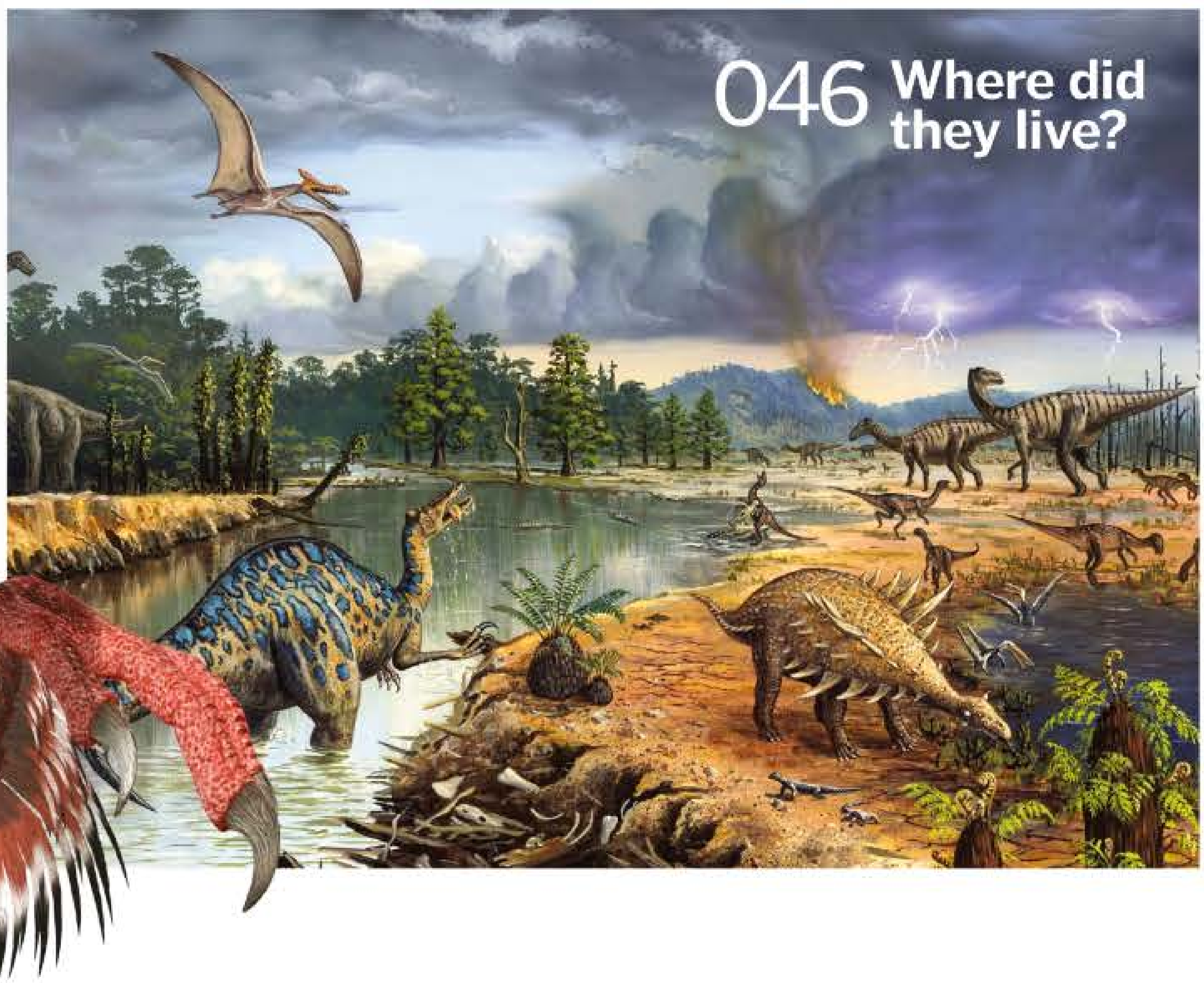

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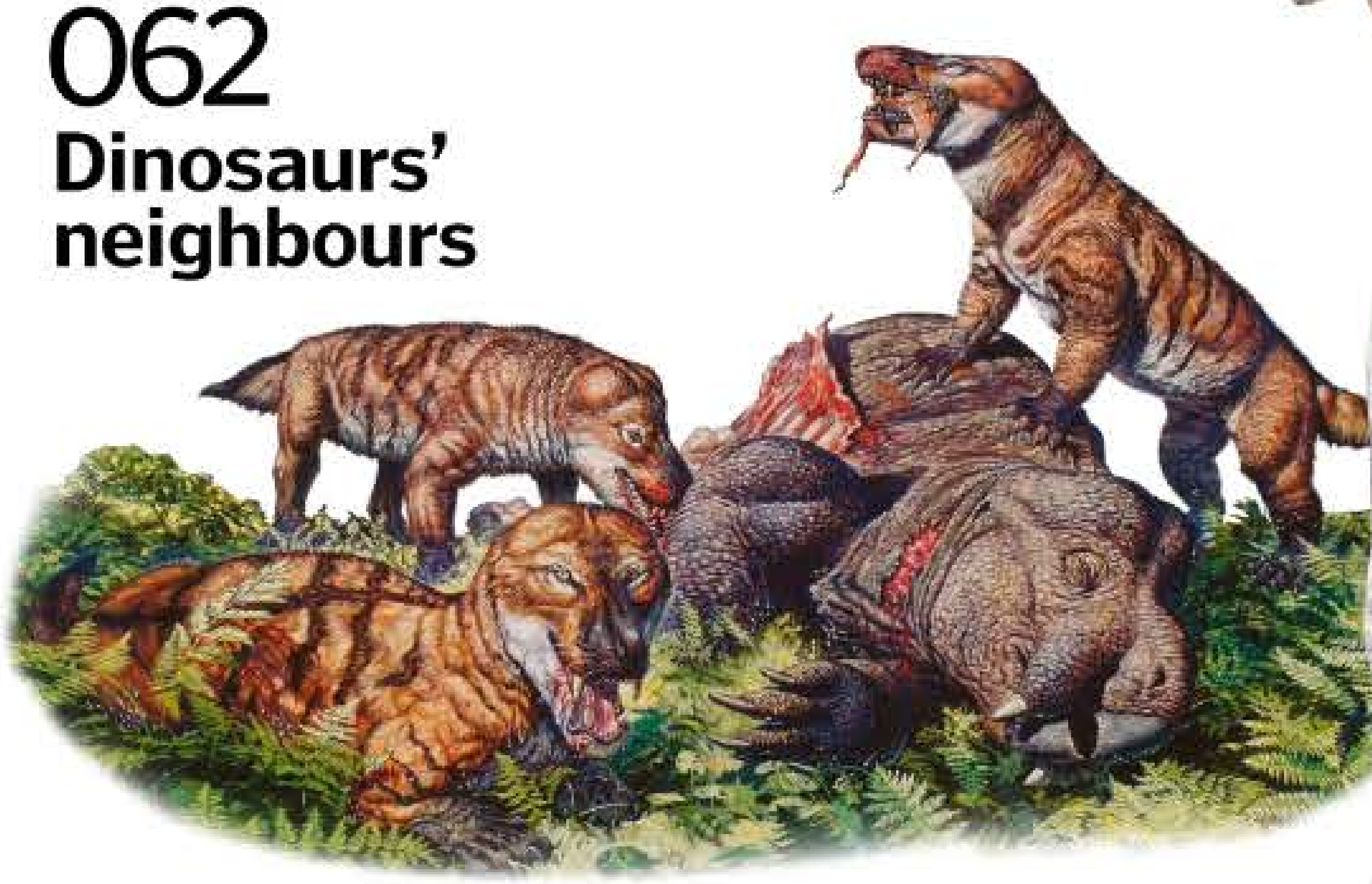


THE WORLD'S MOST AMAZING DINOSAURS

Over 500 types of dinosaur existed before they died out 65 million years ago. Here's 26 of the biggest, fiercest and weirdest known to palaeontologists today

Tyrannosaurus rex

('Tyrant lizard king')

Carnivore

Cretaceous period, 67-66 MYA

Found in: ***Western North America***

Lived in: ***Forests with swamps and rivers***

Long-lived
T-rex was able to live for up to 30 years

Balance
T-rex's huge head was balanced by its heavy tail

Scales or feathers?
T-rex may have had feathers on at least part of its giant body, just like a bird

Clawed grip
Although T-rex's arms were small, each with two claws, they were strong, able to grip prey or push itself off the floor

Fact

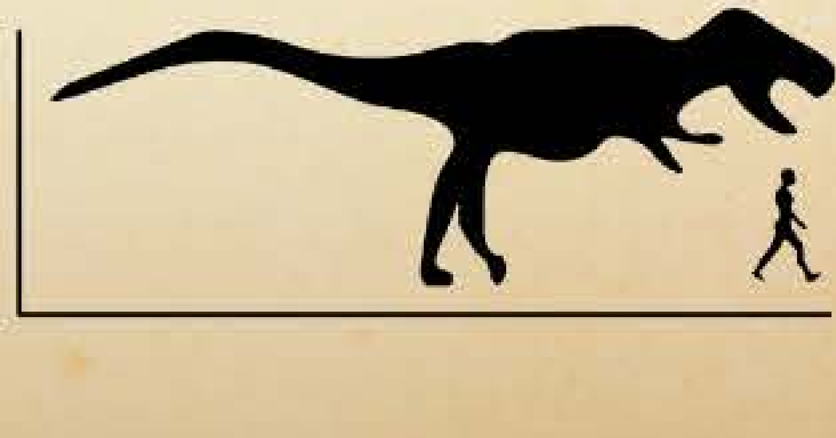
The largest T-rex skulls ever to be found are 1.5m across, and some of the T-rex teeth were up to 30cm long

Dino skill

Tyrannosaurus rex

T-rex may have had one of the most vicious bites of any animal to have lived, many times stronger than lions and sharks and capable of crunching bone and ripping apart its prey.

Killer rating:	**5/5**
Speed:	**3/5**
Defence:	**3/5**



DID YOU KNOW? T-rex jaws were so powerful they could crunch through bone

Stegosaurus

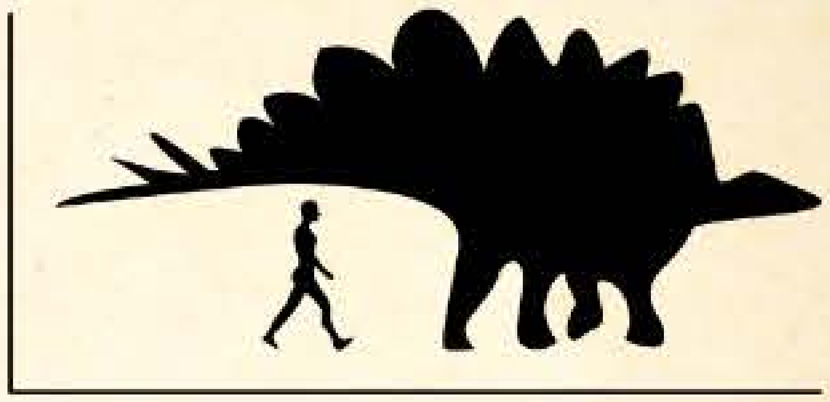
('Roof lizard')

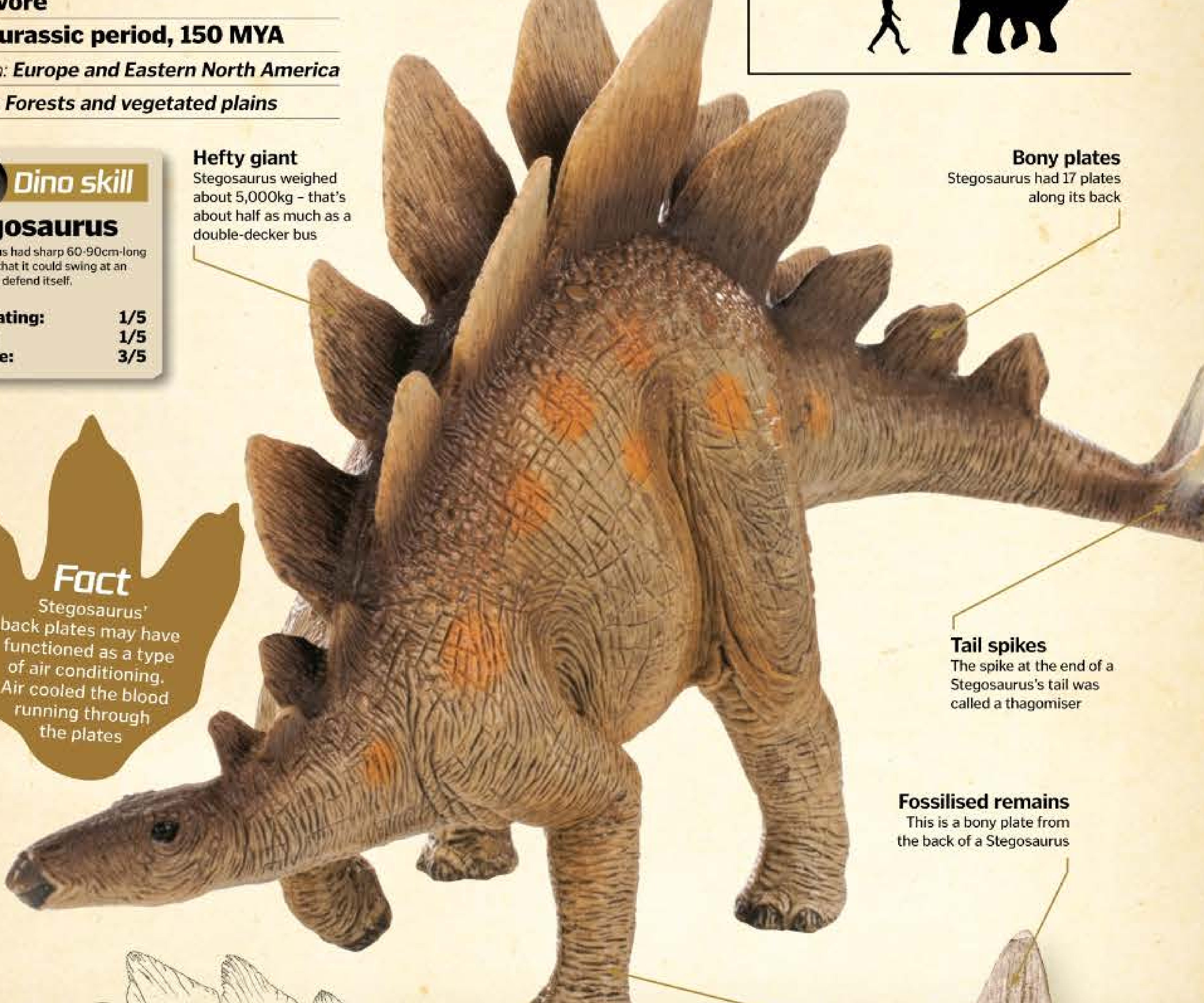
Herbivore

Late Jurassic period, 150 MYA

Found in: ***Europe and Eastern North America***

Lived in: ***Forests and vegetated plains***





Dino skill

Stegosaurus

Stegosaurus had sharp 60-90cm-long tail spikes that it could swing at an attacker to defend itself.

Killer rating:	**1/5**
Speed:	**1/5**
Defence:	**3/5**

Fact

Stegosaurus' back plates may have functioned as a type of air conditioning. Air cooled the blood running through the plates

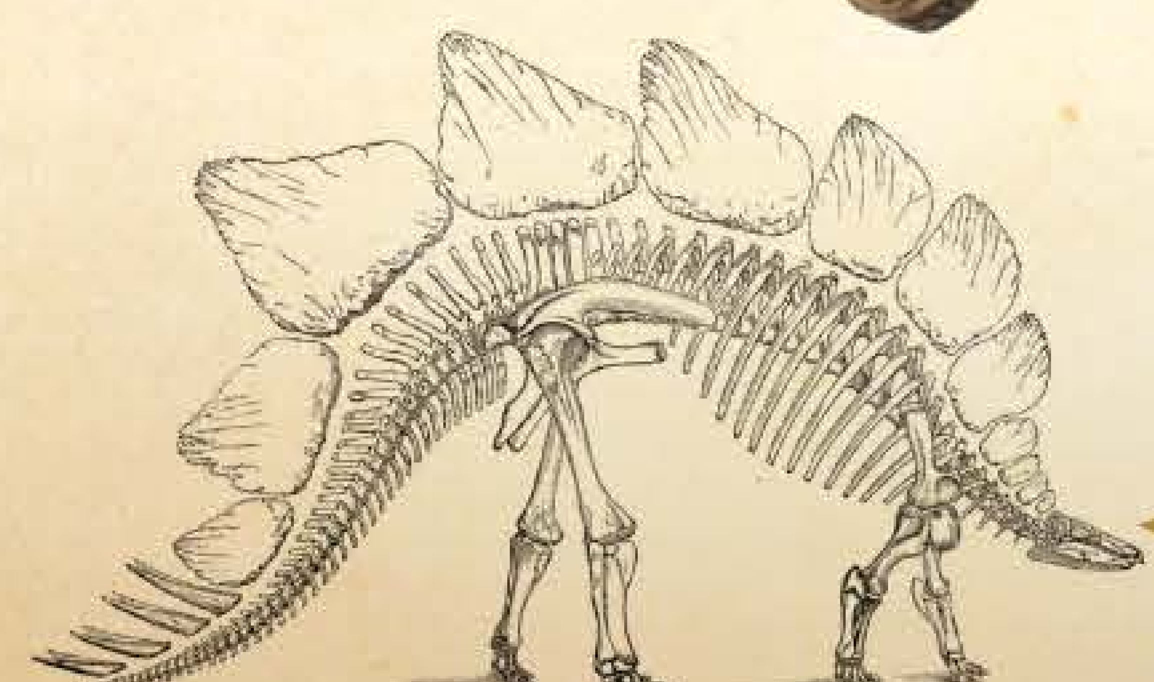
Hefty giant
Stegosaurus weighed about 5,000kg – that's about half as much as a double-decker bus

Bony plates
Stegosaurus had 17 plates along its back

Tail spikes
The spike at the end of a Stegosaurus's tail was called a thagomiser

Fossilised remains
This is a bony plate from the back of a Stegosaurus

Slow and steady
Its short, stumpy legs meant that Stegosaurus could barely walk faster than a human being



Brain power
Stegosaurus was not a very smart dinosaur – it had a brain no larger than a dog's

Triceratops

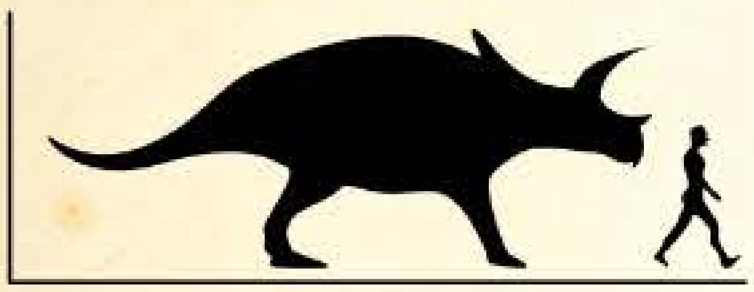
('Three-horn face')

Herbivore

Late Cretaceous, 67-65 MYA

Found in: ***Western North America***

Lived in: ***Forests with prairies***



Dino skill

Triceratops

Triceratops' three horns and frill were used for courtships and combat, using them to take on and beat the dreaded Tyrannosaurus rex.

Killer rating:	**2/5**
Speed:	**2/5**
Defence:	**4/5**

Fact

During their lifetime Triceratops would go through between a massive 400 to 800 teeth as they browsed on ferns

Velociraptor

('Swift plunderer')

Carnivore

Cretaceous period, 75-71 MYA

Found in: ***China, Mongolia***

Lived in: ***Desert***

Warm-blooded
Velociraptors were probably warm-blooded

Feathered fiend
Though long thought to be scaly (as pictured here), it's now believed that velociraptors had feathers that were used for display, covering nests or providing added speed when running

Fact

In the *Jurassic Park* films Velociraptors were tall and scaly, but in reality they were more like large birds and were much, much smaller

Small size
Velociraptors were small, like a large chicken

Dino skill

Velociraptor

Velociraptors were loners, hunting other small dinosaurs by launching surprise attacks and then chasing down their prey.

Killer rating:	**2/5**
Speed:	**2/5**
Defence:	**4/5**

Hunting
Their curved claw was a frightening weapon, able to stab and cut open prey

Pounce
They had very strong back legs and sharp claws on their feet

Brachiosaurus

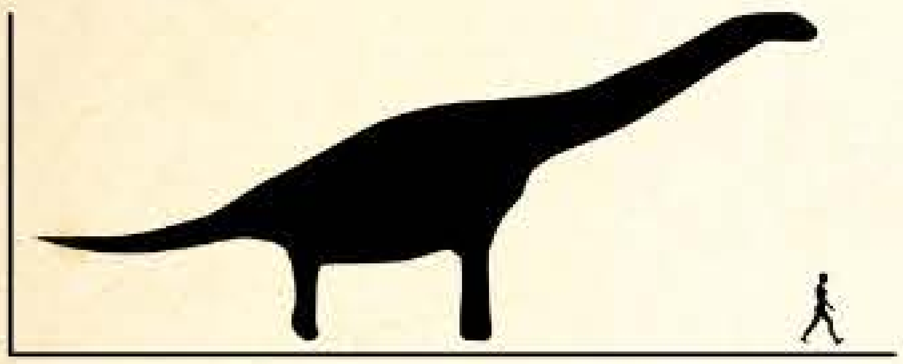
('Arm lizard')

Herbivore

Jurassic period, 150 MYA

Found in: ***North America***

Lived in: ***Forests***



Dino skill

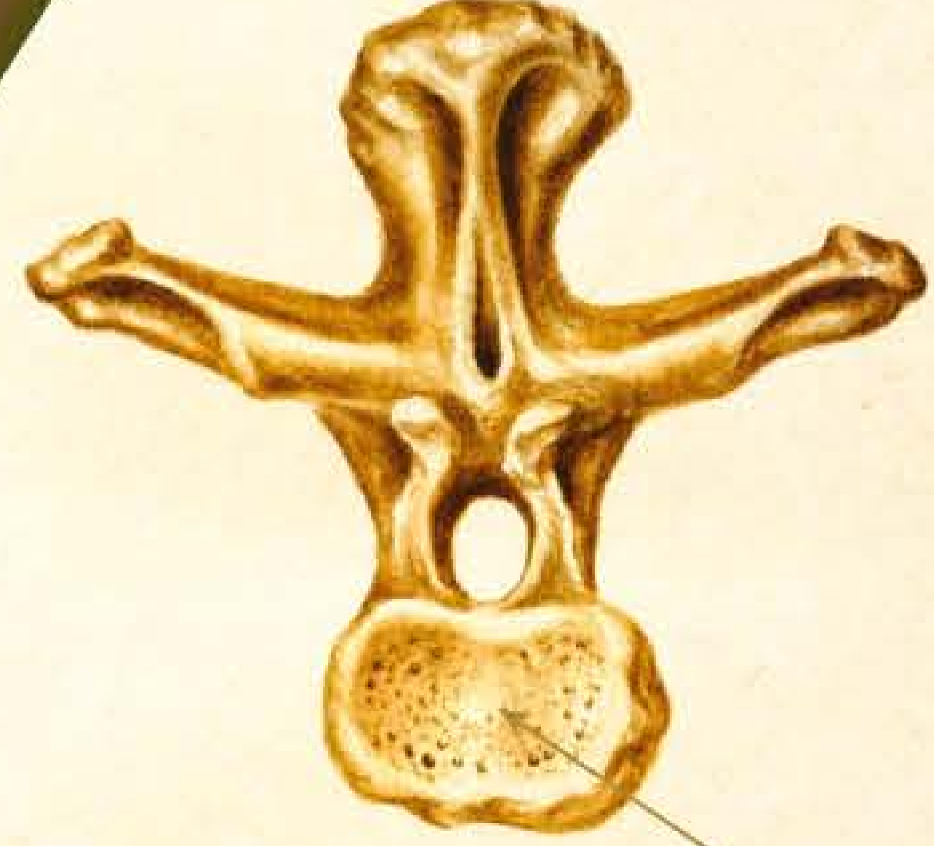
Brachiosaurus

Brachiosaurus just spent its day lumbering around, so wasn't particularly skilful, but it was so large that no predator could harm it.

Killer rating:	**1/5**
Speed:	**1/5**
Defence:	**4/5**

Fact

Brachiosaurus constantly ate. It's thought that it ate between 200 and 400kg of plants every day – that's like eating 400 to 800 lettuces



Diplodocus

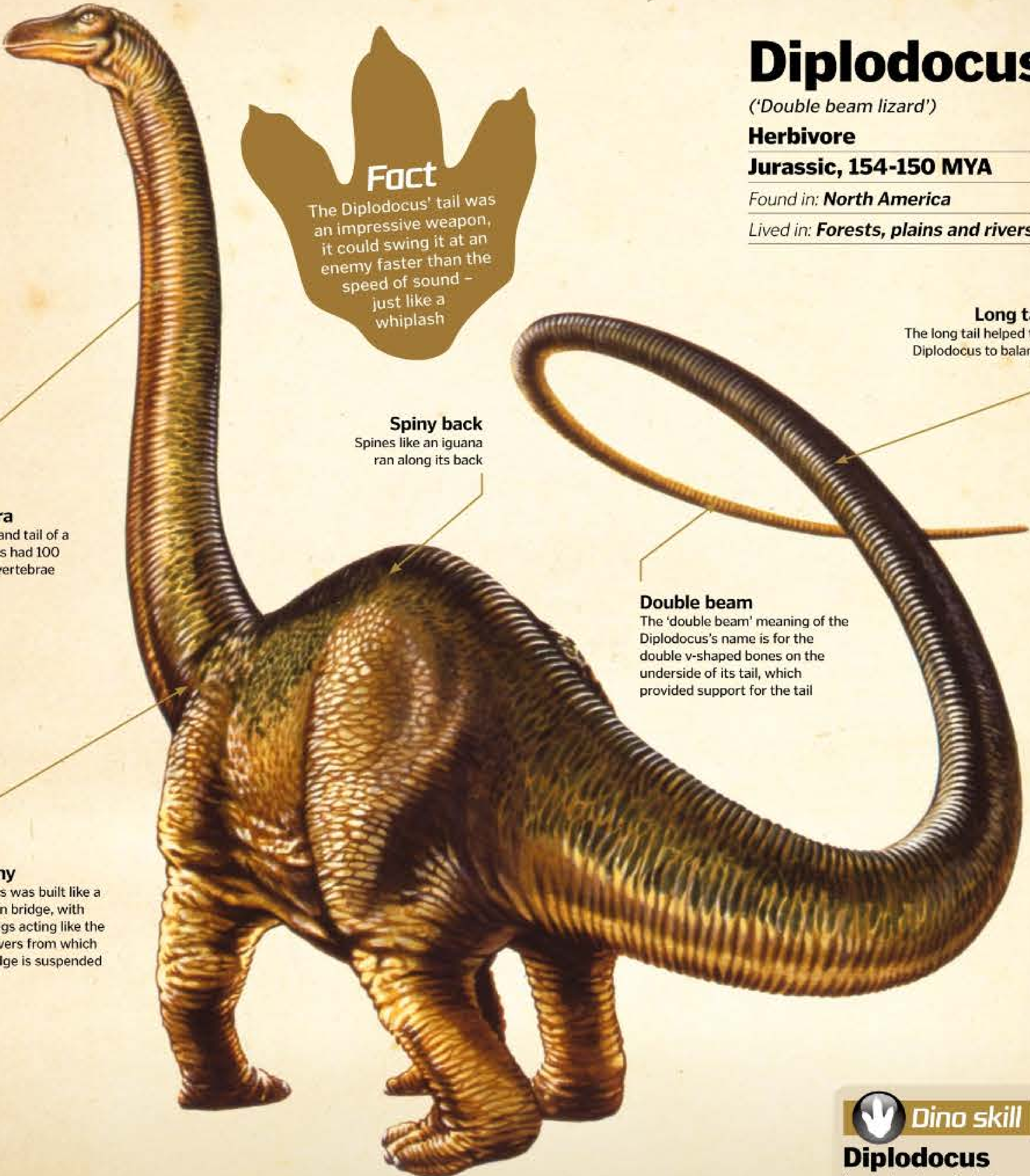
('Double beam lizard')

Herbivore

Jurassic, 154-150 MYA

Found in: ***North America***

Lived in: ***Forests, plains and rivers***



Fact
The Diplodocus' tail was an impressive weapon, it could swing it at an enemy faster than the speed of sound – just like a whiplash

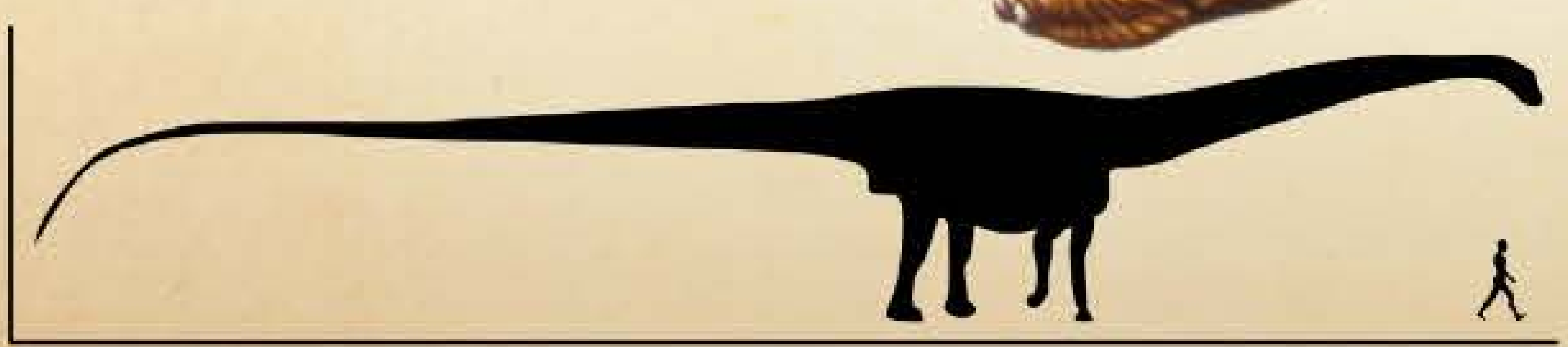
Spiny back
Spines like an iguana ran along its back

Long tail
The long tail helped the Diplodocus to balance

Vertebra
The neck and tail of a Diplodocus had 100 bones or vertebrae

Double beam
The 'double beam' meaning of the Diplodocus's name is for the double v-shaped bones on the underside of its tail, which provided support for the tail

Anatomy
Diplodocus was built like a suspension bridge, with the four legs acting like the pair of towers from which a long bridge is suspended



Dino skill

Diplodocus

An extra-long claw on its thumb allowed Diplodocus to rake through branches and vegetation for food, as well as using the claw to defend itself from predators.

Killer rating:	**1/5**
Speed:	**3/5**
Defence:	**3/5**

Allosaurus

('Different lizard')

Carnivore

Late Jurassic, 155-150 MYA

Found in: ***North America***

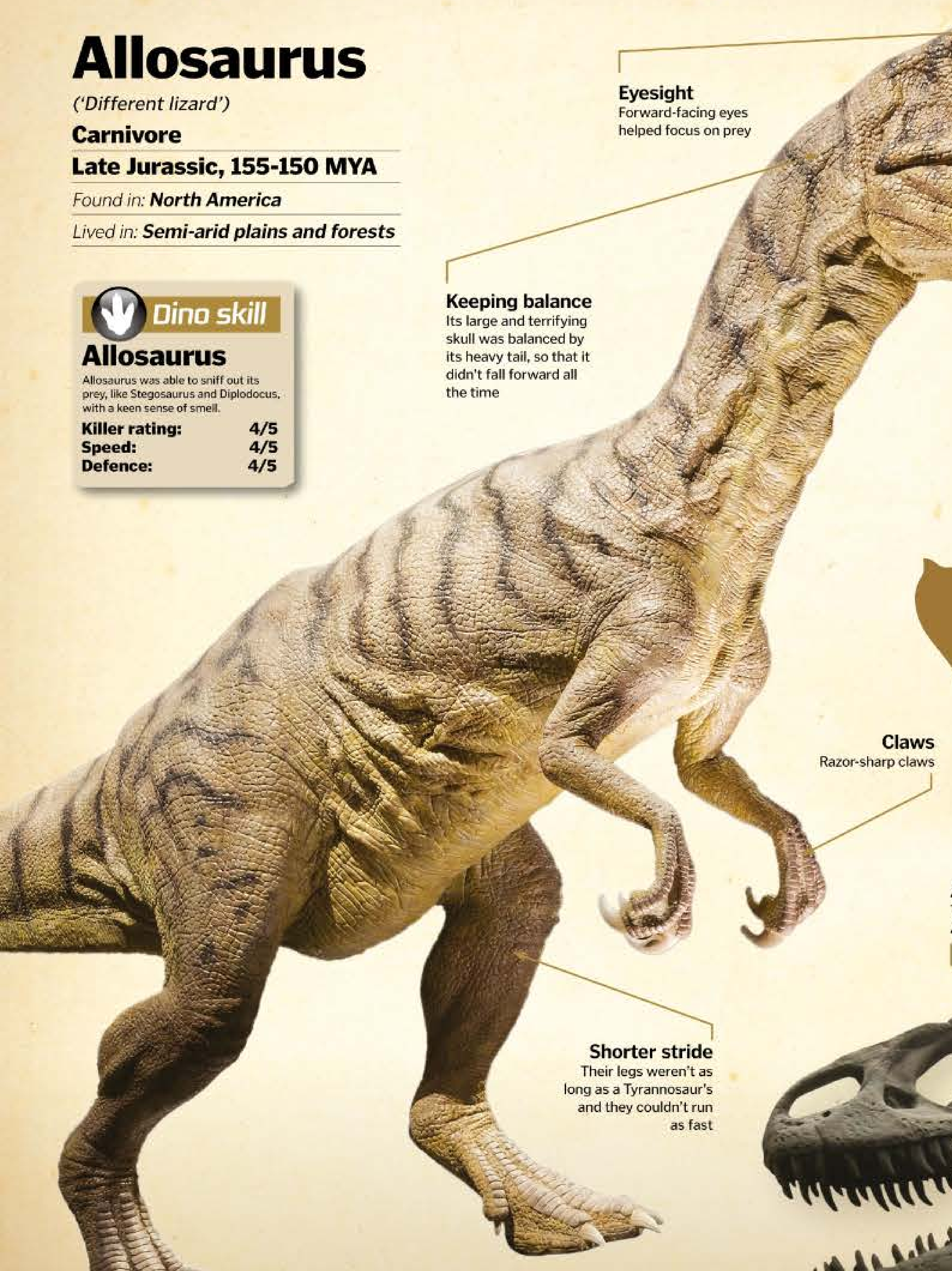
Lived in: ***Semi-arid plains and forests***

Dino skill

Allosaurus

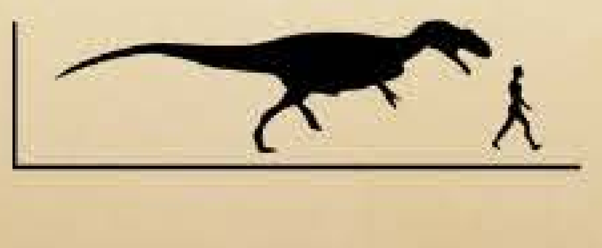
Allosaurus was able to sniff out its prey, like Stegosaurus and Diplodocus, with a keen sense of smell.

Killer rating:	**4/5**
Speed:	**4/5**
Defence:	**4/5**



Fact

Allosaurus' backward-facing, 10cm-long teeth meant that it could continuously push its prey further down its mouth



Spinosaurus

('Spine lizard')

Carnivore

Cretaceous period, 112-97 MYA

Found in: ***North Africa***

Lived in: ***Forests***

Largest carnivore
Spinosaurus was taller than T-rex

Fact
Spinosaurus is the largest meat-eating dinosaur that has ever existed, bigger than a T-rex. Its diet consisted of fish and land animals

Sail back
The giant 1.5m spine, sometimes called its 'sail', could have been used to attract mates, control body temperature and warn off competitors

Crocodile-like
Its head was the longest of any carnivorous dinosaur, the size of a human being, and was shaped like a crocodile's head

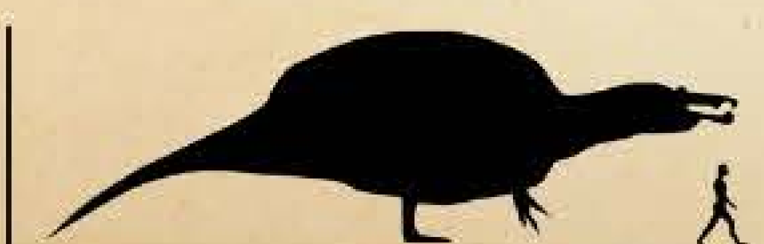
Grasping arms
Claws on its small arms could grab prey

Dino skill

Spinosaurus

Its teeth were arranged in a 'fish trap' at the front of its mouth to better catch slippery fish, while its nostrils were turned inward, so it could eat and breathe at the same time while in the water.

Killer rating:	**4/5**
Speed:	**4/5**
Defence:	**4/5**



Argentinosaurus

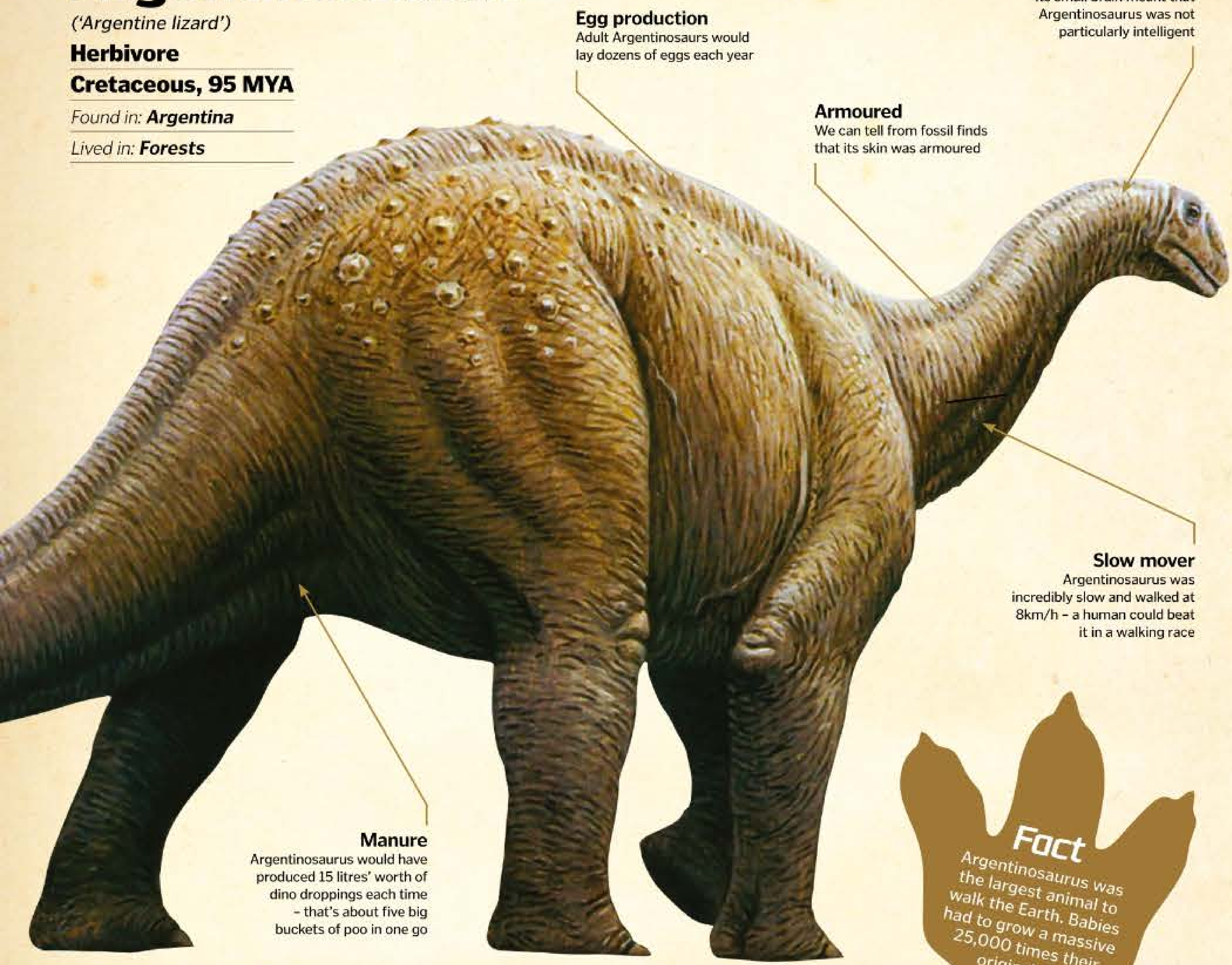
('Argentine lizard')

Herbivore

Cretaceous, 95 MYA

Found in: ***Argentina***

Lived in: ***Forests***



Fact

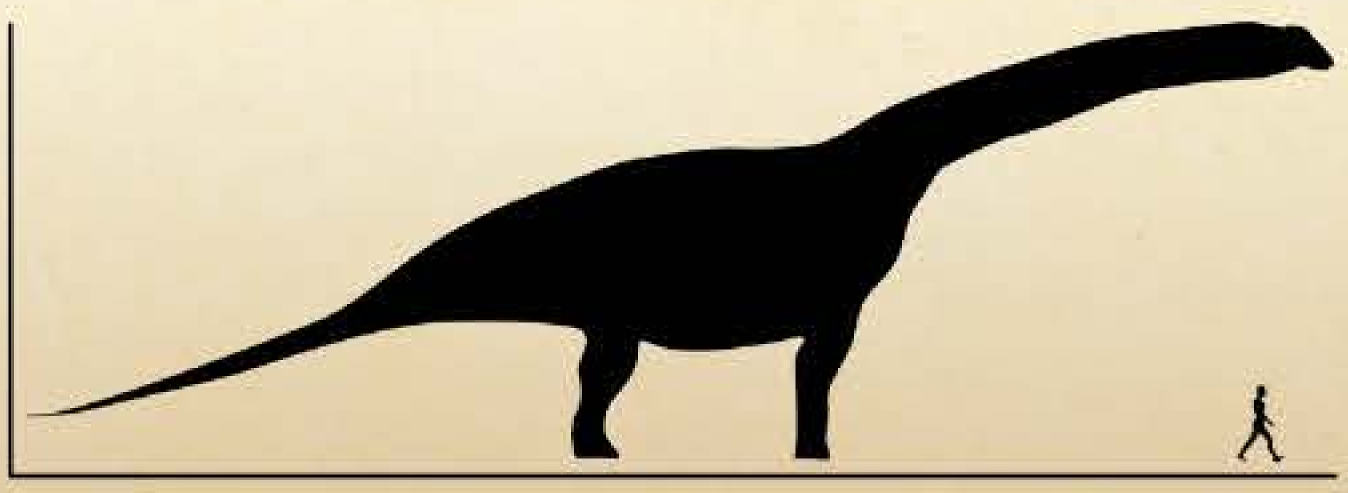
Argentinosaurus was the largest animal to walk the Earth. Babies had to grow a massive 25,000 times their original size

Dino skill

Argentinosaurus

Argentinosaurus had the ability to stand up on its back legs, then come crashing down on any attackers.

Killer rating:	**2/5**
Speed:	**1/5**
Defence:	**3/5**



Carnotaurus

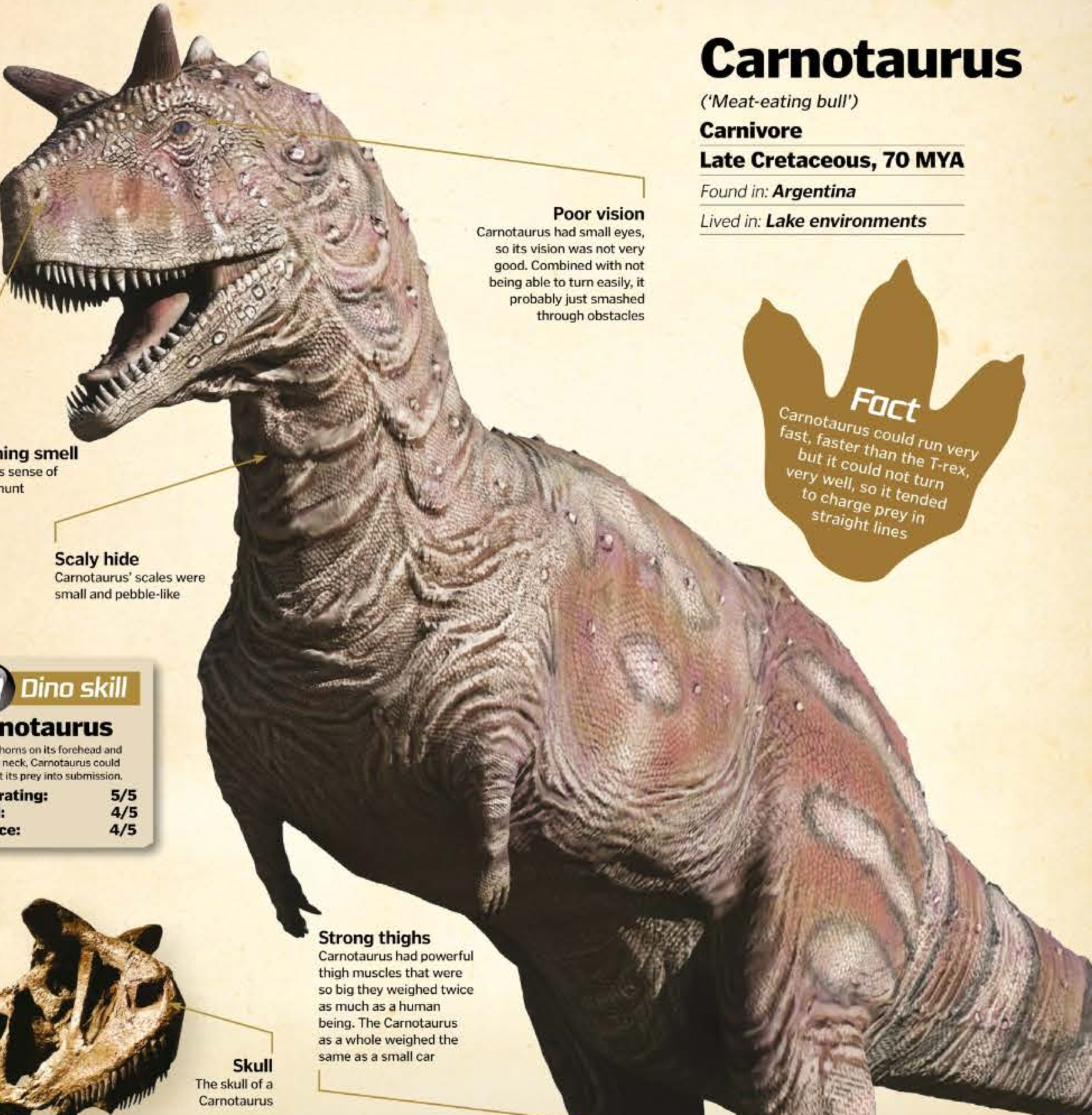
('Meat-eating bull')

Carnivore

Late Cretaceous, 70 MYA

Found in: ***Argentina***

Lived in: ***Lake environments***



Poor vision
Carnotaurus had small eyes, so its vision was not very good. Combined with not being able to turn easily, it probably just smashed through obstacles

Searching smell
It used its sense of smell to hunt

Scaly hide
Carnotaurus' scales were small and pebble-like

Strong thighs
Carnotaurus had powerful thigh muscles that were so big they weighed twice as much as a human being. The Carnotaurus as a whole weighed the same as a small car

Fact
Carnotaurus could run very fast, faster than the T-rex, but it could not turn very well, so it tended to charge prey in straight lines

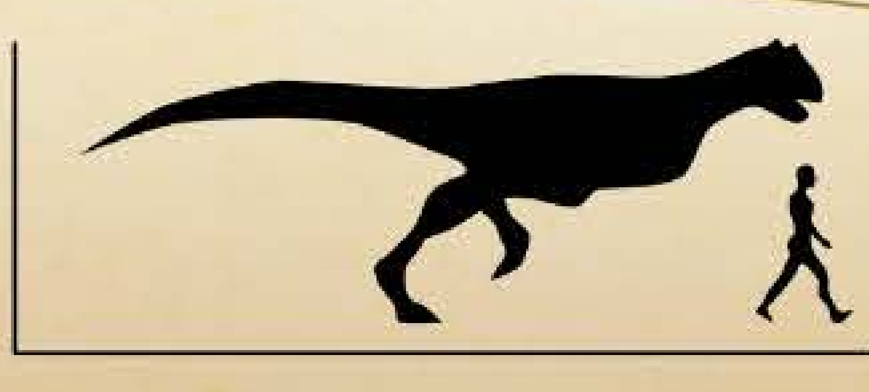
Dino skill

Carnotaurus

With the horns on its forehead and muscular neck, Carnotaurus could head-butt its prey into submission.

Killer rating:	**5/5**
Speed:	**4/5**
Defence:	**4/5**

Skull
The skull of a Carnotaurus



Sinosauropteryx

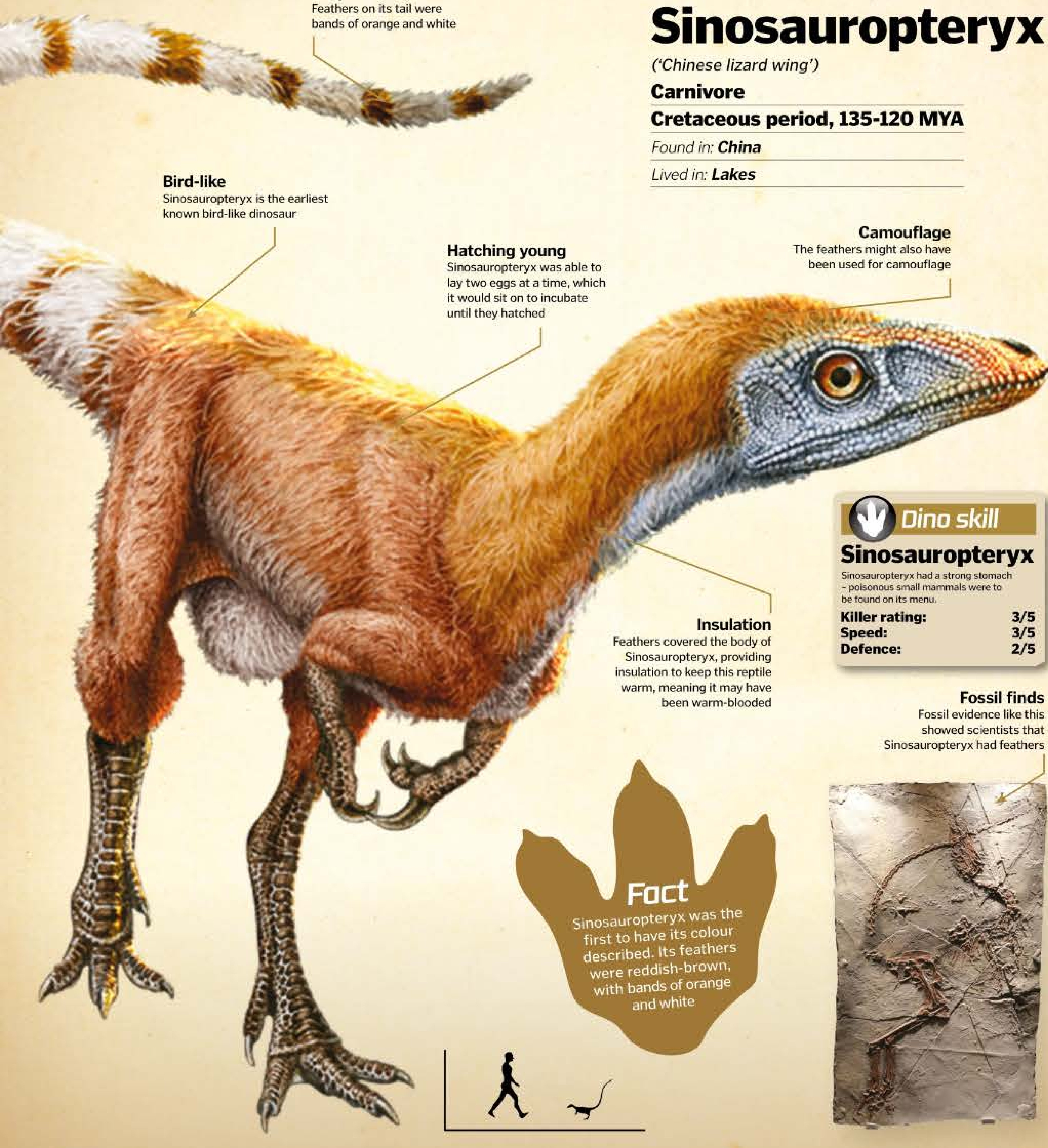
('Chinese lizard wing')

Carnivore

Cretaceous period, 135-120 MYA

Found in: ***China***

Lived in: ***Lakes***



Dino skill

Sinosauropteryx

Sinosauropteryx had a strong stomach – poisonous small mammals were to be found on its menu.

Killer rating:	**3/5**
Speed:	**3/5**
Defence:	**2/5**

Fossil finds
Fossil evidence like this showed scientists that Sinosauropteryx had feathers

Fact

Sinosauropteryx was the first to have its colour described. Its feathers were reddish-brown, with bands of orange and white

Ankylosaurus

('Fused lizard')

Herbivore

Cretaceous, 70-65 MYA

Found in: ***South America***

Lived in: ***Coastal plains***

Dino skill

Ankylosaurus

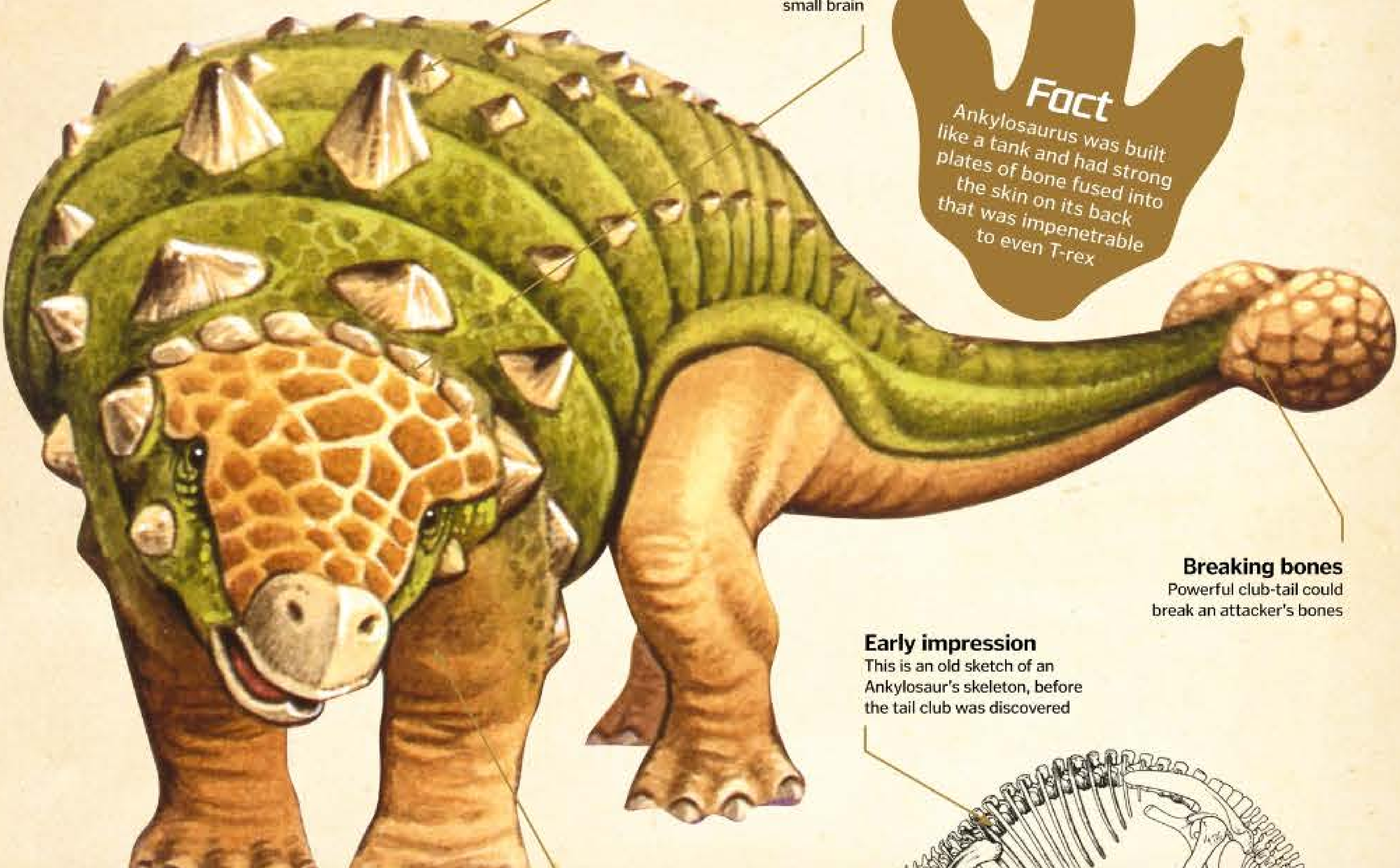
Its club-like tail was a vicious weapon that the Ankylosaurus could use to defend itself from attack.

Killer rating:	**3/5**
Speed:	**3/5**
Defence:	**5/5**

Spiky defence
Two rows of spikes ran along its body, plus there were two large horns from the back of its head that it could defend itself with

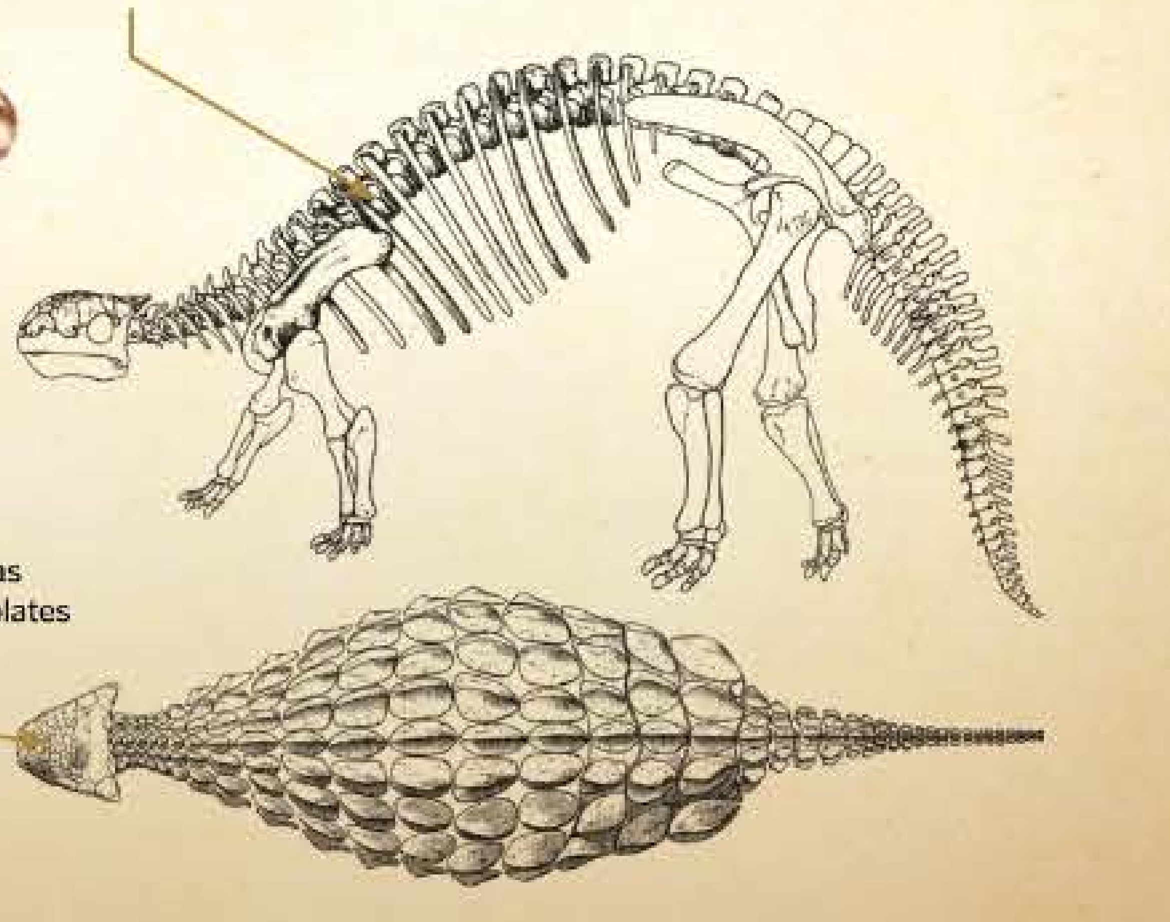
Small brained
The Ankylosaurus had a small brain

Fact
Ankylosaurus was built like a tank and had strong plates of bone fused into the skin on its back that was impenetrable to even T-rex



Breaking bones
Powerful club-tail could break an attacker's bones

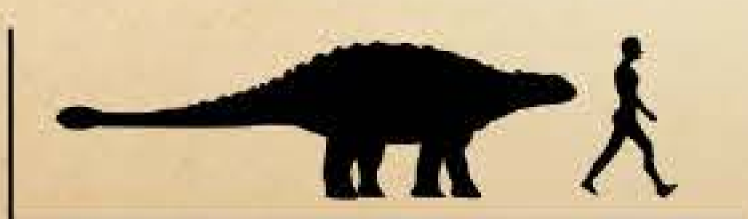
Early impression
This is an old sketch of an Ankylosaur's skeleton, before the tail club was discovered



Five-toed
Ankylosaurus probably had five toes on each foot

Vulnerable
The underside of its belly was the only place the Ankylosaurus was not armoured – flipping it over was the only way to kill it

Bone head
Its entire head was covered in bony plates



Archaeopteryx

('First bird')

Carnivore

Jurassic period, 150 MYA

Found in: ***Germany***

Lived in: ***Subtropical islands***

Sharp teeth
Sharp teeth made Archaeopteryx an efficient predator

Fly or glide?
It is unclear whether Archaeopteryx was able to flap its wings and fly, or more likely whether it could just glide

Dark feathers
Tips of feathers coloured black

Killer claws
Archaeopteryx had three claws on each wing, plus killing claws on its feet, with which would hunt for insects and small reptiles

Fact
As well as being a dinosaur, the Archaeopteryx is also the first known bird and was about the size of a pigeon, although it had more teeth

Dino skill

Archaeopteryx

Its wings were made for gliding only short distances – instead Archaeopteryx was well adapted to spending most of its time living in trees.

Killer rating:	**2/5**
Speed:	**2/5**
Defence:	**2/5**

Compsognathus

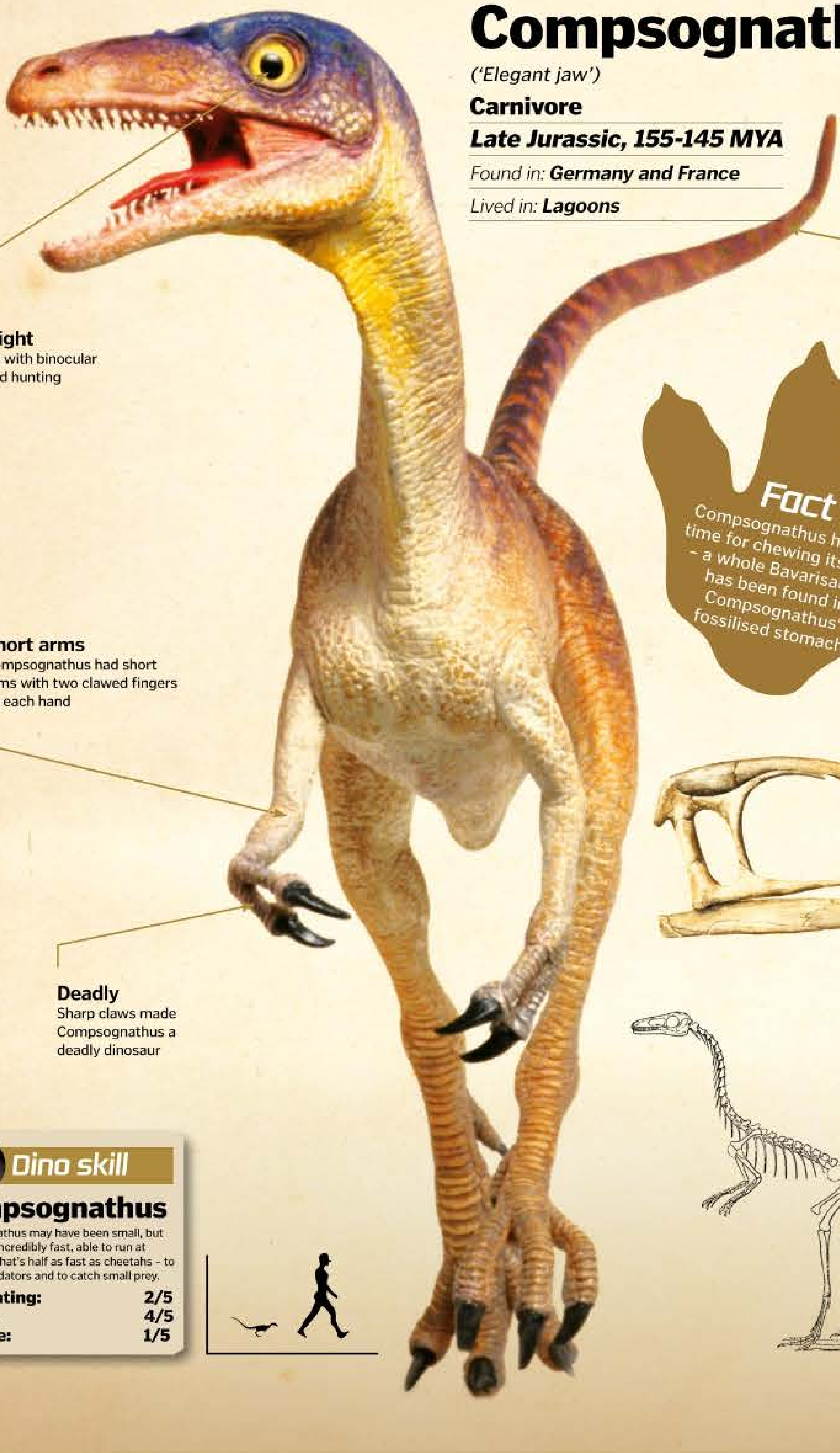
('Elegant jaw')

Carnivore

Late Jurassic, 155-145 MYA

Found in: ***Germany and France***

Lived in: ***Lagoons***



Sharp sight
Large eyes with binocular vision aided hunting

Equilibrium
To help it run fast, its long tail helped to give the Compsognathus balance

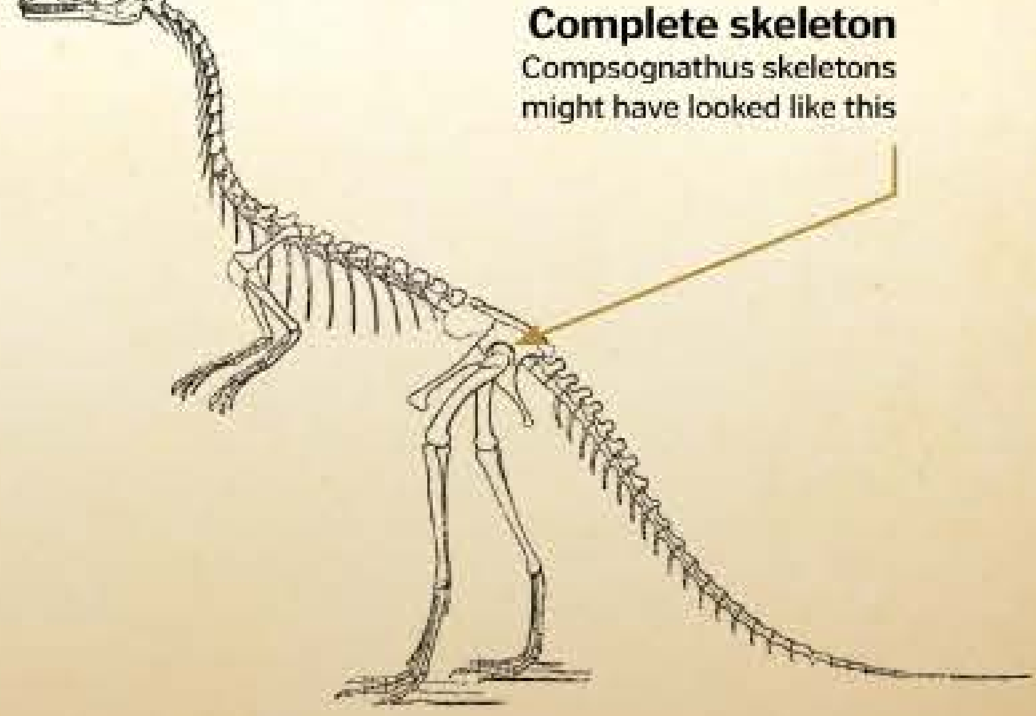
Fact
Compsognathus had no time for chewing its food – a whole Bavarisaurus has been found in Compsognathus' fossilised stomach

Short arms
Compsognathus had short arms with two clawed fingers on each hand

Pointed teeth
It had a small pointed head with sharp teeth

Deadly
Sharp claws made Compsognathus a deadly dinosaur

Complete skeleton
Compsognathus skeletons might have looked like this



Dino skill

Compsognathus

Compsognathus may have been small, but they were incredibly fast, able to run at 60km/h – that's half as fast as cheetahs – to escape predators and to catch small prey.

Killer rating:	**2/5**
Speed:	**4/5**
Defence:	**1/5**

Herrerasaurus

('Herrera's lizard')

Carnivore

Late Triassic, 231 MYA

Found in: ***Argentina***

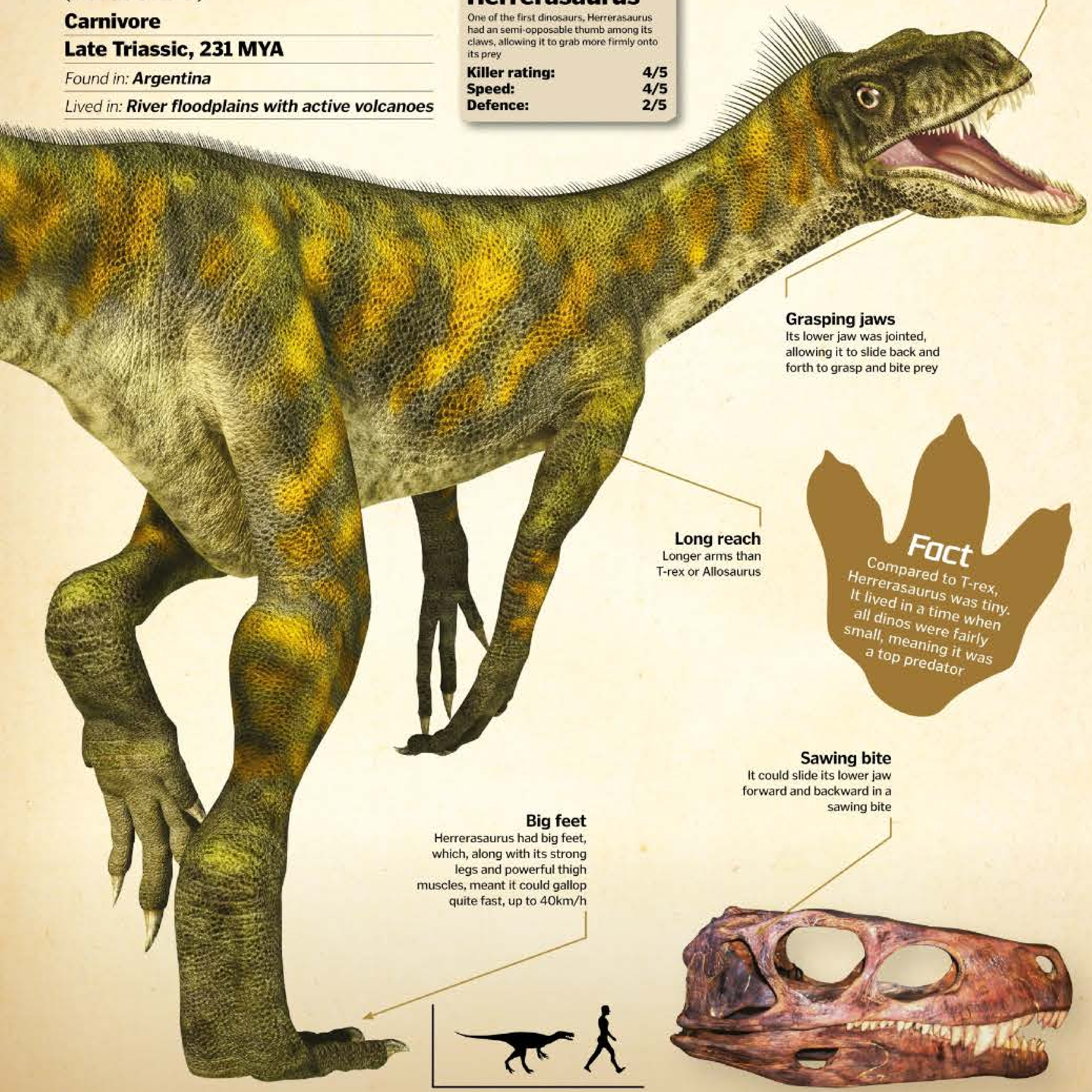
Lived in: ***River floodplains with active volcanoes***

Dino skill

Herrerasaurus

One of the first dinosaurs, Herrerasaurus had an semi-opposable thumb among its claws, allowing it to grab more firmly onto its prey

Killer rating:	**4/5**
Speed:	**4/5**
Defence:	**2/5**



Deadly grip
Inwardly curving teeth allowed it to hang onto its prey

Grasping jaws
Its lower jaw was jointed, allowing it to slide back and forth to grasp and bite prey

Long reach
Longer arms than T-rex or Allosaurus

Fact
Compared to T-rex, Herrerasaurus was tiny. It lived in a time when all dinos were fairly small, meaning it was a top predator

Sawing bite
It could slide its lower jaw forward and backward in a sawing bite

Big feet
Herrerasaurus had big feet, which, along with its strong legs and powerful thigh muscles, meant it could gallop quite fast, up to 40km/h

DID YOU KNOW? *The Jurassic Coast in South-West England stretches 95 miles*

Pachycephalosaurus

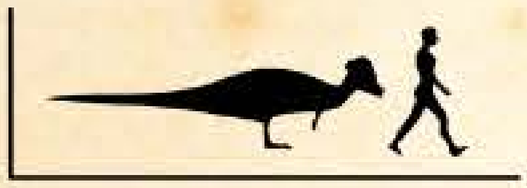
('Thick-headed lizard')

Herbivore

Late Cretaceous, 65-75 MYA

Found in: ***North America, Isle of Wight, Mongolia, Madagascar***

Lived in: ***Coastal regions***



Dino skill

Pachycephalosaurus

Pachycephalosaurus would use its domed head to ram the sides of other animals that attacked it.

Killer rating:	**1/5**
Speed:	**2/5**
Defence:	**3/5**

Armoured skull
Bony dome protected its small brain

Big eyes
It had large eyes compared to many other dinosaurs

Herd life
Pachycephalosaurus found additional safety in numbers – they lived in herds, feeding on plants with their small, sharp teeth

Five fingers
Hands with five-fingered claws

Fighting fit
Some scientists think they used their thick skulls for fighting each other

Running from danger
Despite the powerful legs, Pachycephalosaurus was not much of a sprinter, although its first line of defence from attackers would have been to run

Fact
Bow down to royalty! Pachycephalosaurus wore a crown of spikes on its head, which was protected by a large, bony dome

Deinonychus

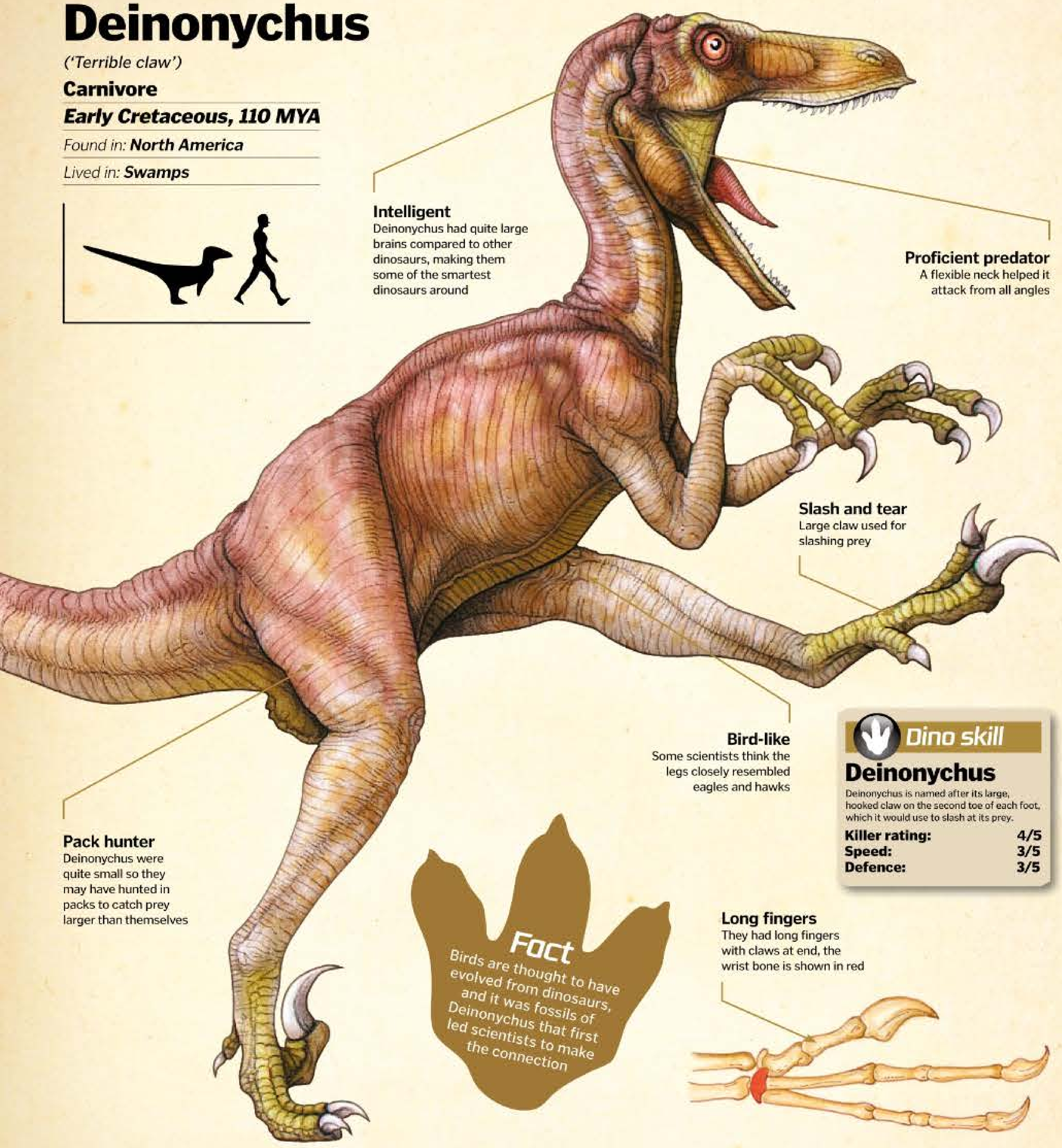
('Terrible claw')

Carnivore

Early Cretaceous, 110 MYA

Found in: ***North America***

Lived in: ***Swamps***



Dino skill

Deinonychus

Deinonychus is named after its large, hooked claw on the second toe of each foot, which it would use to slash at its prey.

Killer rating:	**4/5**
Speed:	**3/5**
Defence:	**3/5**

Fact

Birds are thought to have evolved from dinosaurs, and it was fossils of Deinonychus that first led scientists to make the connection

Long fingers
They had long fingers with claws at end, the wrist bone is shown in red

Euoplocephalus

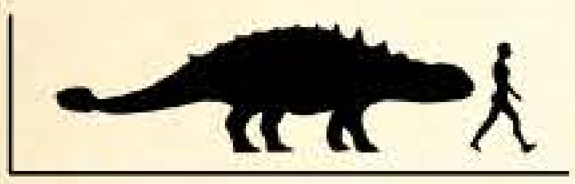
('Well-armed head')

Herbivore

Late Cretaceous, 70 MYA

Found in: ***North America***

Lived in: ***Forests and rivers***



Fact
Dinosaurs had poor eyesight and Euoplocephalus had some of the worst – it probably bumped into things a lot

Defence
Spikes and horns provided additional defence from jaws of carnivores like T-rex

Weight
At 2,000kg Euoplocephalus was twice the weight of a male Indian rhino

Armour plating
Euoplocephalus had armour plates that ran across their entire body, providing ample protection from the jaws of carnivores like T-rex

Bony club
It may have only eaten leaves, but its club-tail could give anyone who made it angry a life-threatening injury

Dino skill

Euoplocephalus

Euoplocephalus would eat many types of plants and to help digest it all they had a large stomach inside a big rib cage and a barrel-shaped abdomen.

Killer rating:	**1/5**
Speed:	**1/5**
Defence:	**4/5**

Iguanodon

('Iguana-tooth')

Herbivore

Early Cretaceous, 130 MYA

Found in: ***Europe, North America, Africa, Asia***

Lived in: ***Forests, plains and rivers***

Dino skill

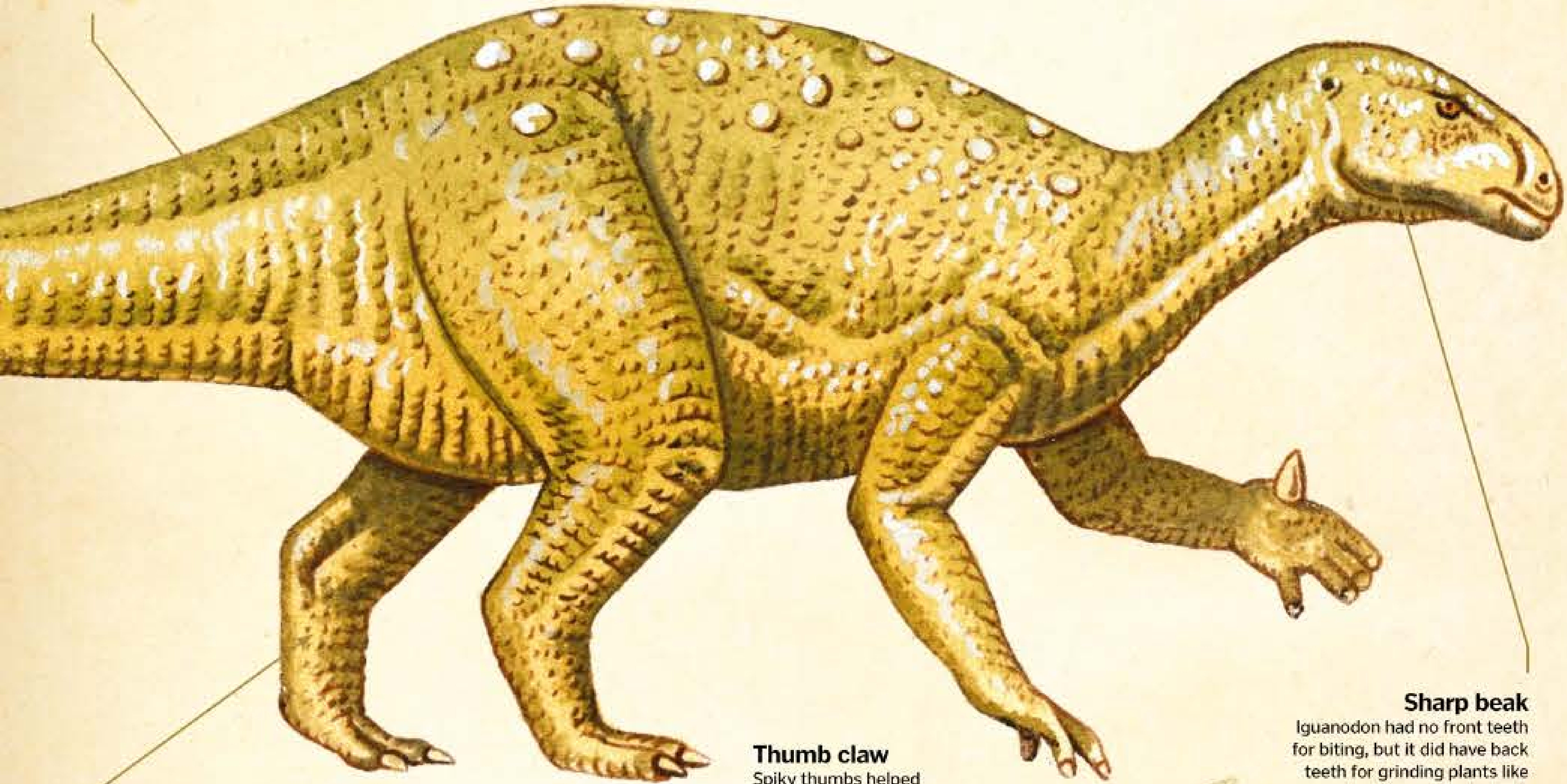
Iguanodon

The Iguanodon's claws also had a thumb spike, which could have been used to help grab food, as well as fend off any attackers that got too close.

Killer rating:	**1/5**
Speed:	**3/5**
Defence:	**2/5**

Fact

Most dinosaurs stayed in one region but Iguanodons spent a lot of time moving, to all continents except Antarctica

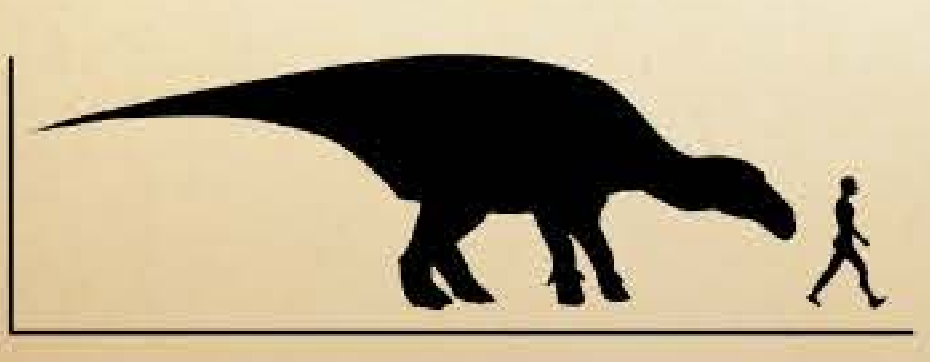


Tail
Iguanodon had a long, stiff tail

Sharp beak
Iguanodon had no front teeth for biting, but it did have back teeth for grinding plants like a modern iguana, and a beak to pick at the plants

Thumb claw
Spiky thumbs helped Iguanodon grapple things

Walk or run?
Iguanodon's legs were longer than its arms and it could walk on all fours or run on its back legs at up to 20kmhh



Seismosaurus

('Quake lizard')

Herbivore

Late Jurassic, 156-145 MYA

Found in: **North America**

Lived in: **Forests, plains and rivers**

Dino skill

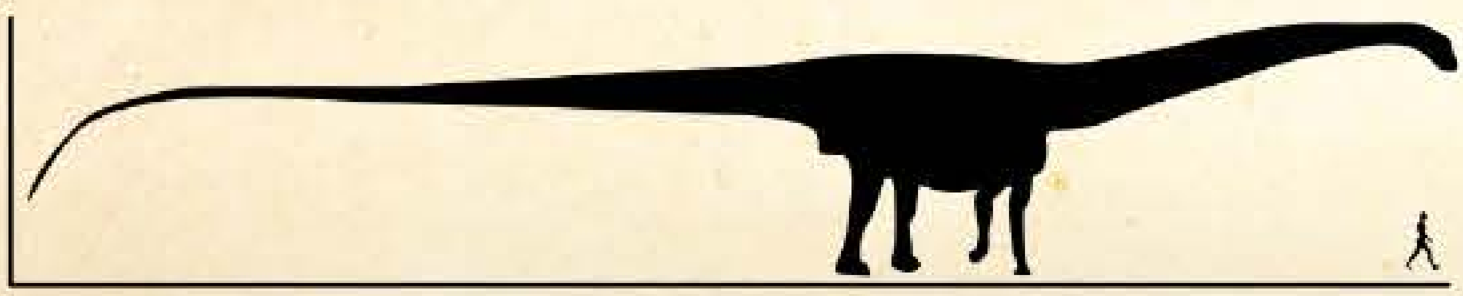
Seismosaurus

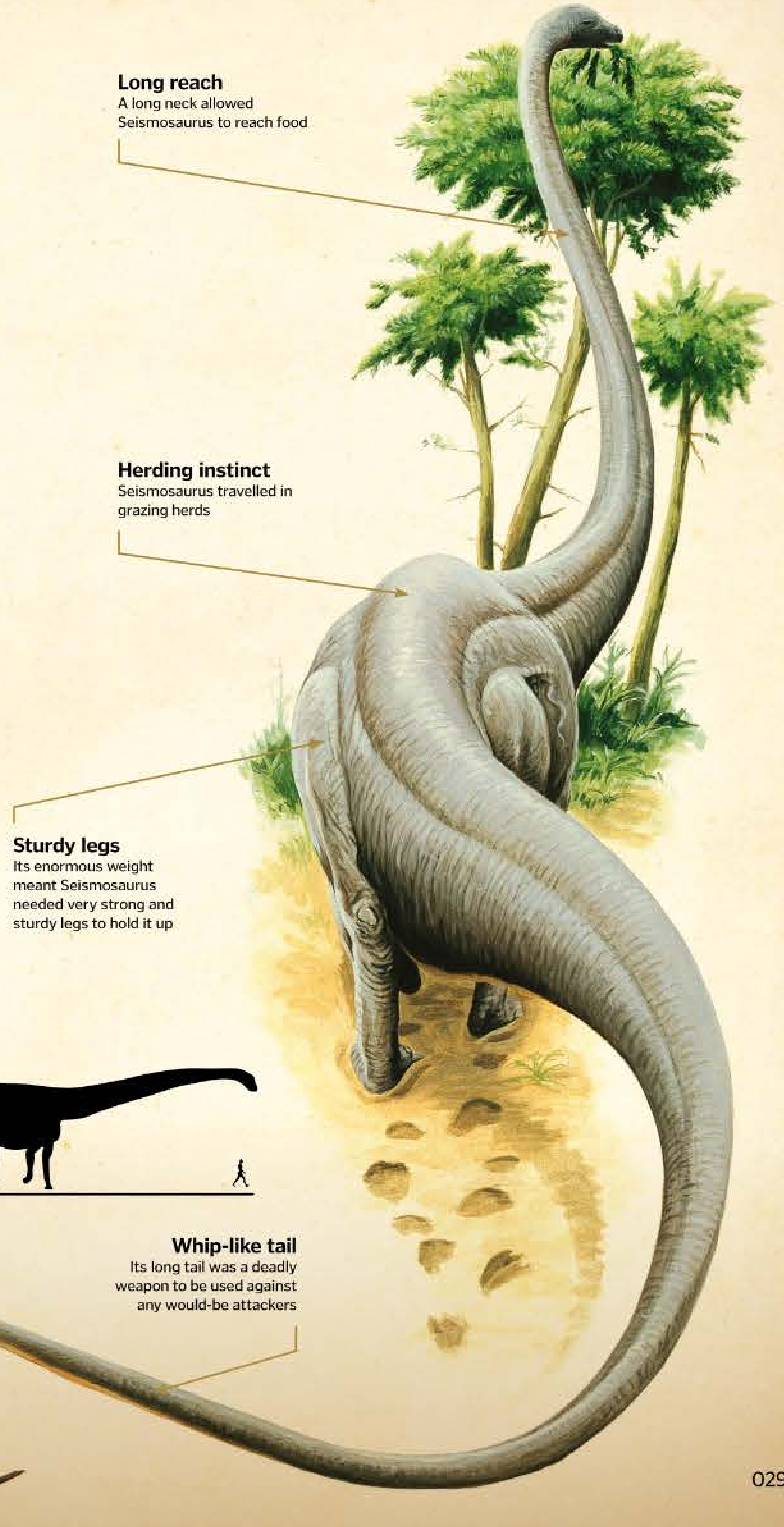
Its long neck ended in a small head armed with peg-like teeth that could strip entire woodlands of their leaves and other foliage in no time at all!

Killer rating:	**1/5**
Speed:	**1/5**
Defence:	**4/5**

Fact

Seismosaurus is a giant version of the Diplodocus. The ground would have shaken when this beast lumbered past





Ouranosaurus

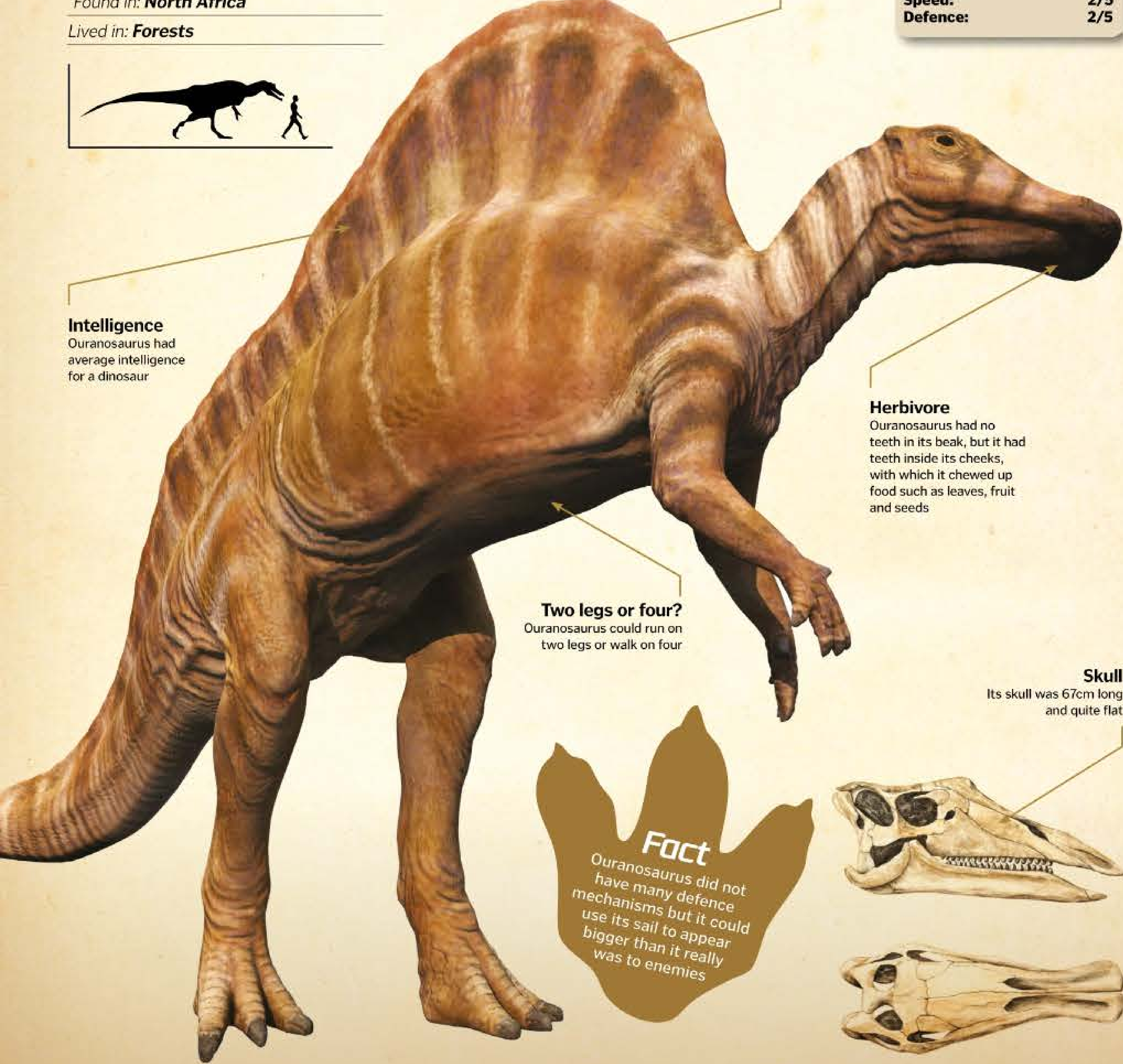
('Brave lizard')

Herbivore

Early Cretaceous, 115-110 MYA

Found in: ***North Africa***

Lived in: ***Forests***



Sail
The distinctive spine ran across the length of Ouranosaurus' back and besides keeping the dinosaur cool, could have stored energy for the winter

Intelligence
Ouranosaurus had average intelligence for a dinosaur

Herbivore
Ouranosaurus had no teeth in its beak, but it had teeth inside its cheeks, with which it chewed up food such as leaves, fruit and seeds

Two legs or four?
Ouranosaurus could run on two legs or walk on four

Skull
Its skull was 67cm long and quite flat

Dino skill

Ouranosaurus

Like Spinosaurus and Stegosaurus, the large sail on the spine of Ouranosaurus helped to regulate its temperature.

Killer rating:	**1/5**
Speed:	**2/5**
Defence:	**2/5**

Fact

Ouranosaurus did not have many defence mechanisms but it could use its sail to appear bigger than it really was to enemies

Dilophosaurus

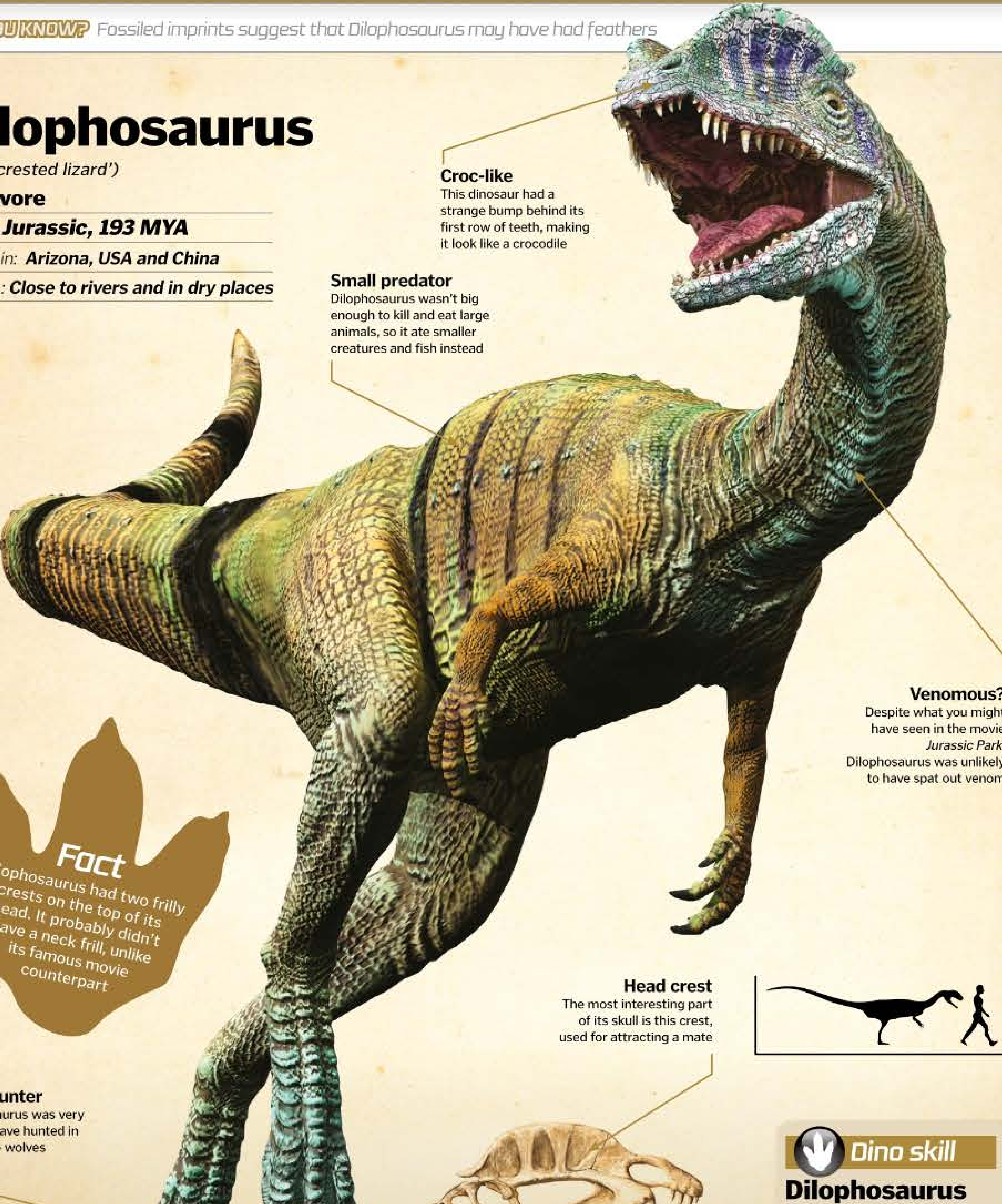
('Two-crested lizard')

Carnivore

Early Jurassic, 193 MYA

Found in: **Arizona, USA and China**

Lived in: ***Close to rivers and in dry places***



Croc-like
This dinosaur had a strange bump behind its first row of teeth, making it look like a crocodile

Small predator
Dilophosaurus wasn't big enough to kill and eat large animals, so it ate smaller creatures and fish instead

Venomous?
Despite what you might have seen in the movie *Jurassic Park*, Dilophosaurus was unlikely to have spat out venom

Fact
Dilophosaurus had two frilly crests on the top of its head. It probably didn't have a neck frill, unlike its famous movie counterpart

Head crest
The most interesting part of its skull is this crest, used for attracting a mate

Pack hunter
Dilophosaurus was very likely to have hunted in packs like wolves

Dino skill

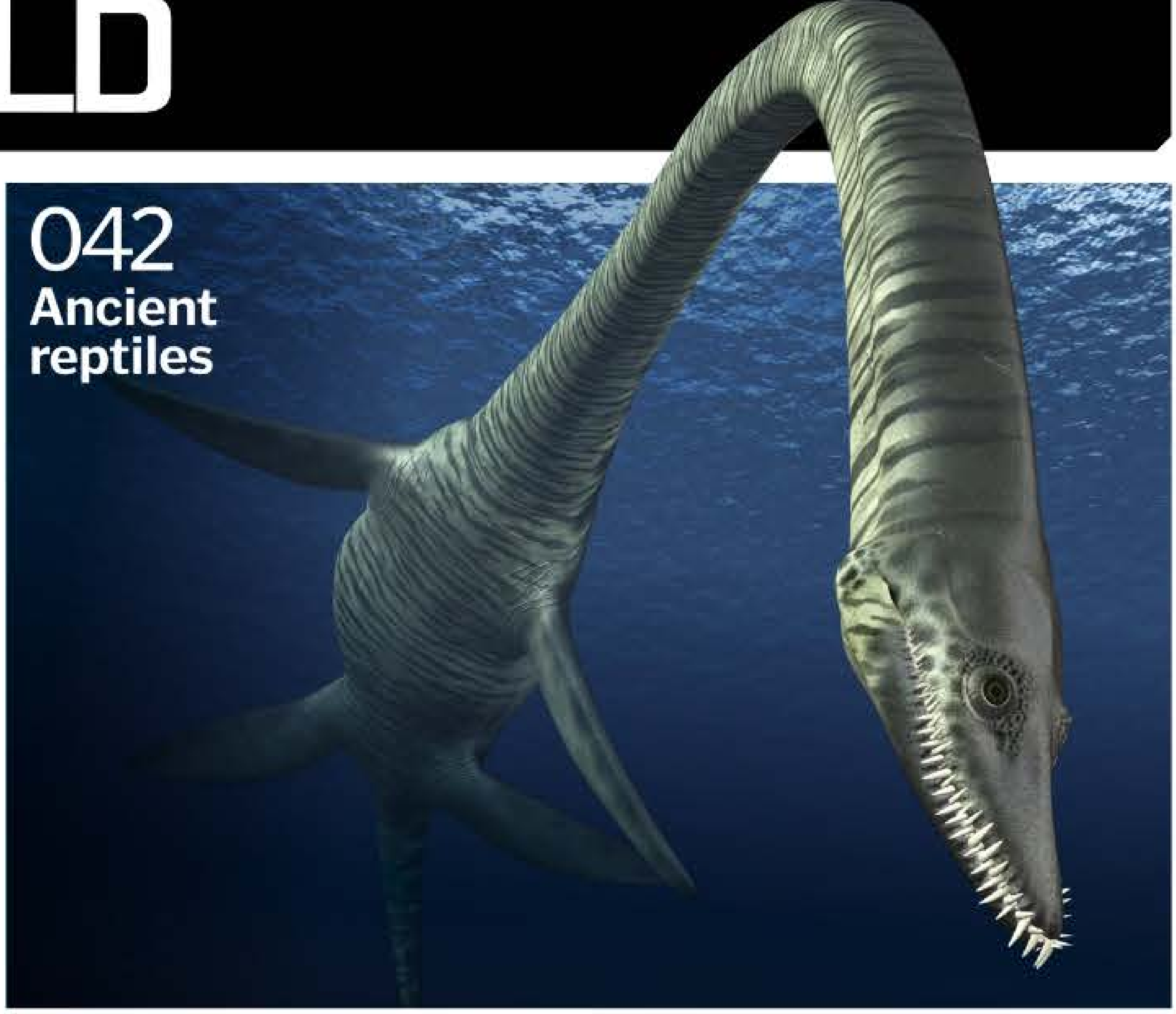
Dilophosaurus

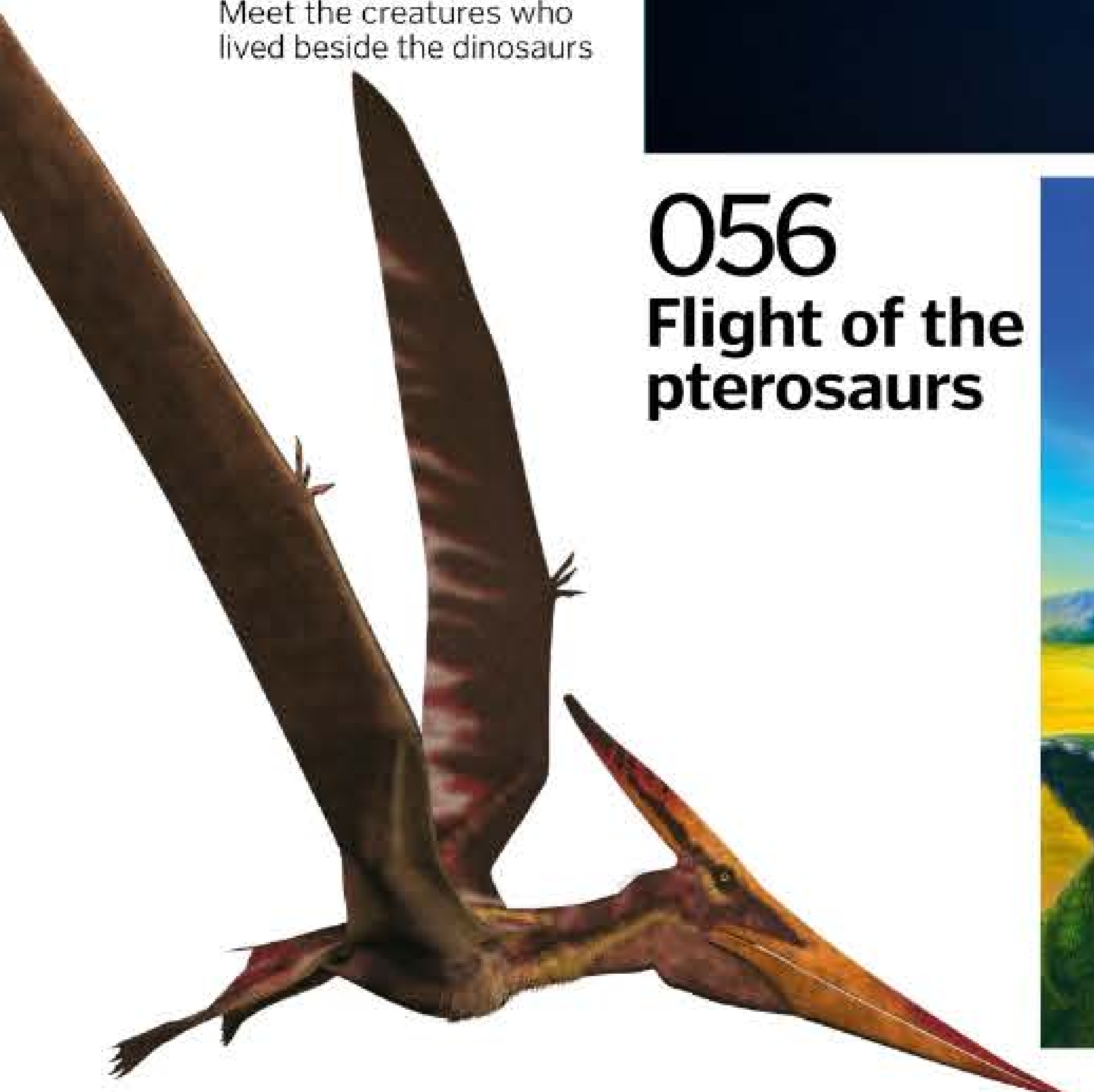
Dilophosaurus was one of the largest predators of its time, during the Early Jurassic period. Fossilised footprints suggest that it hunted in packs.

Killer rating:	**3/5**
Speed:	**2/5**
Defence:	**3/5**

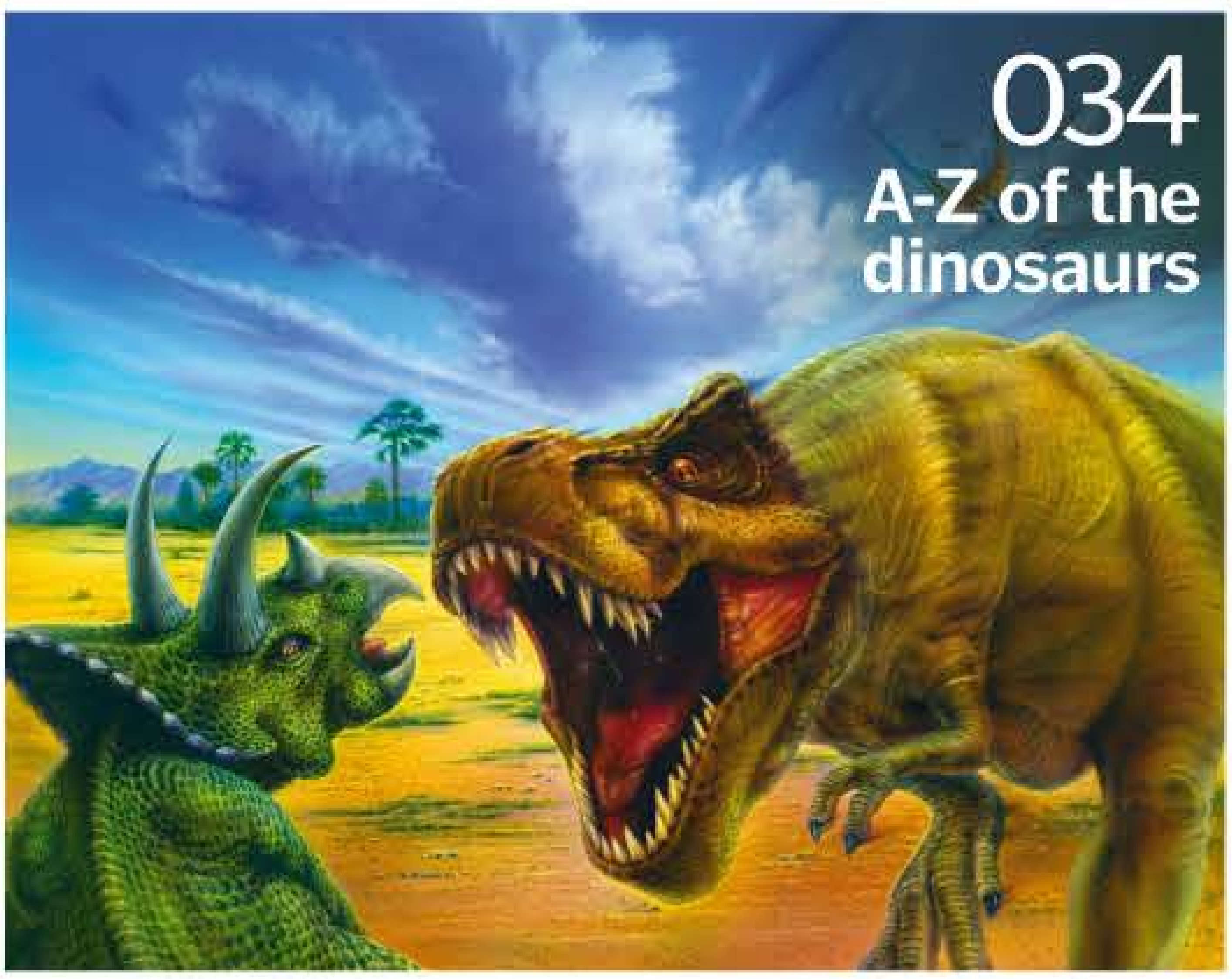
THE PREHISTORIC WORLD

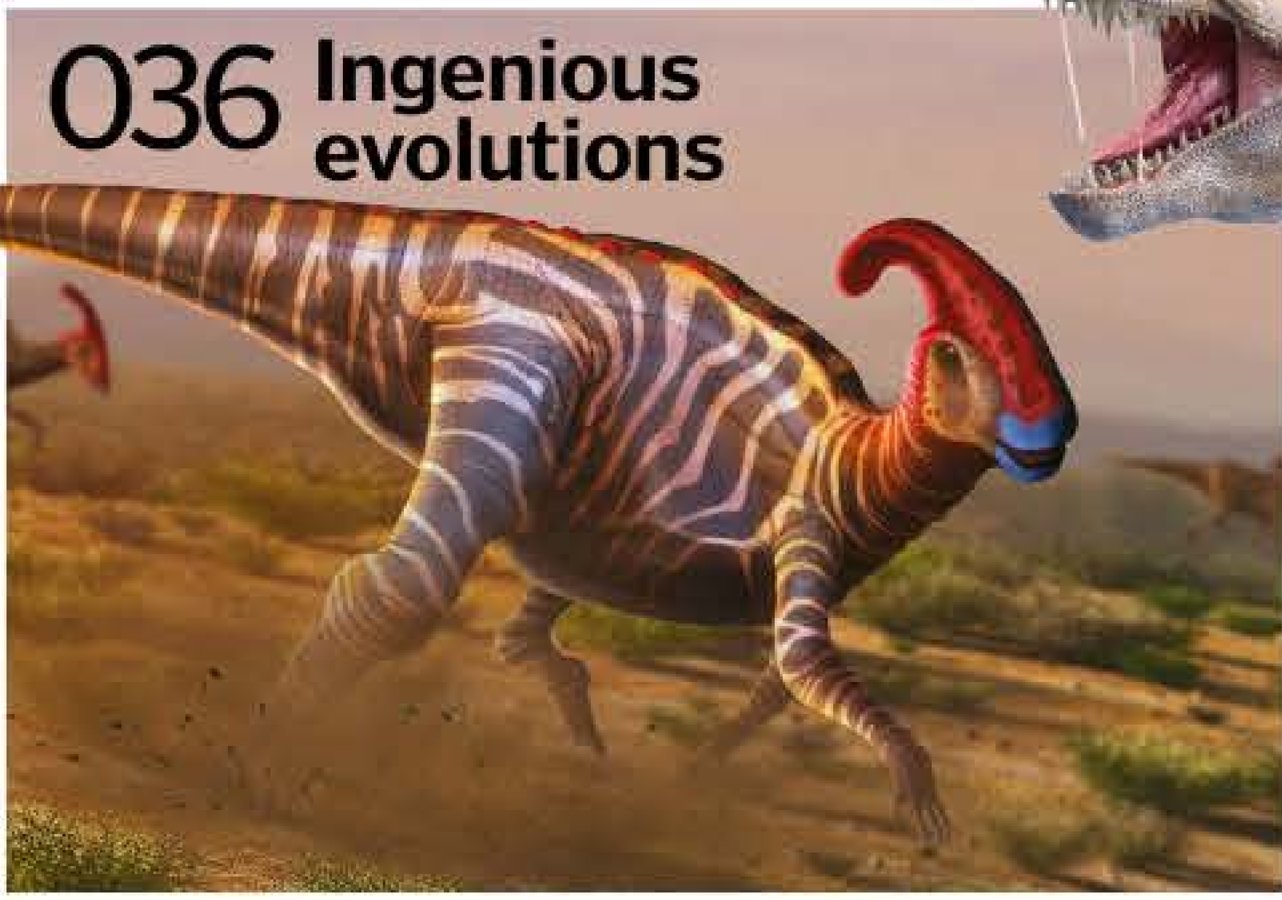
The prehistoric world





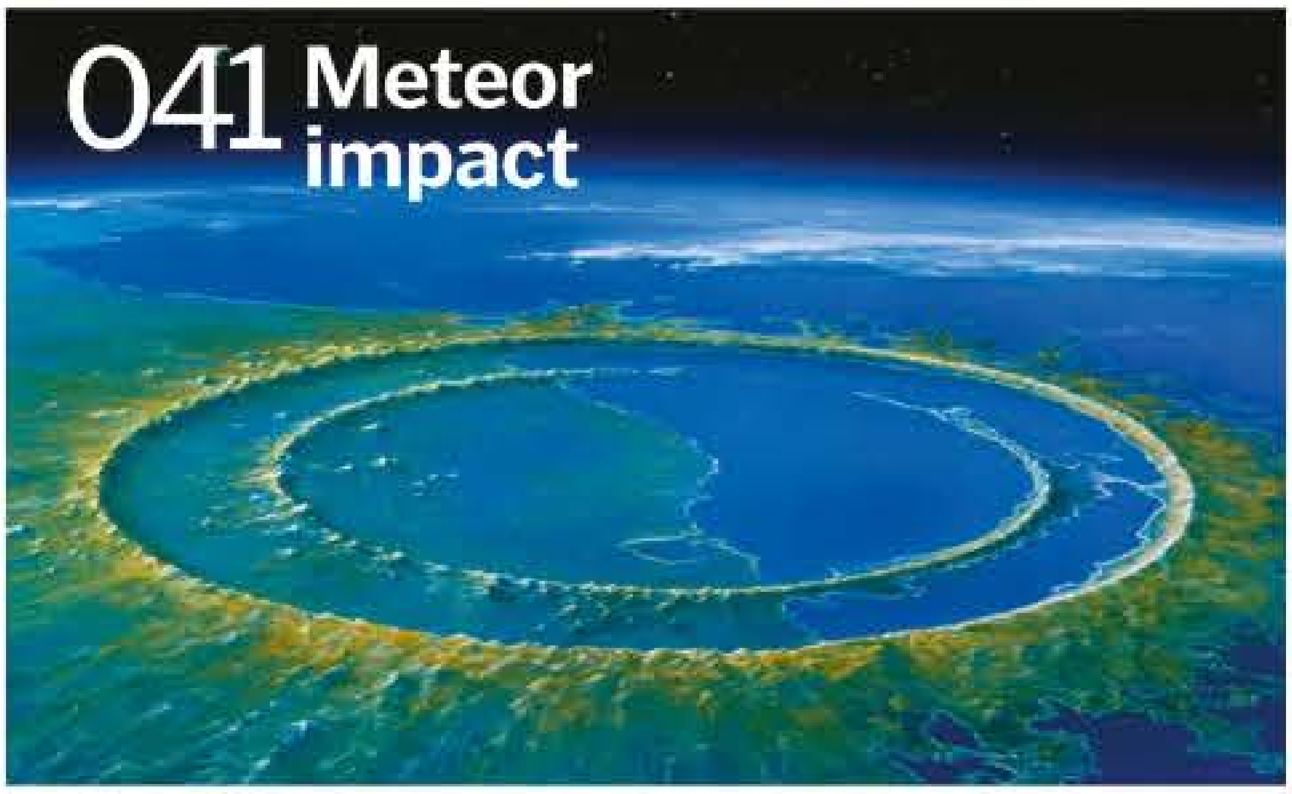
056
Flight of the pterosaurs





036 Ingenious evolutions

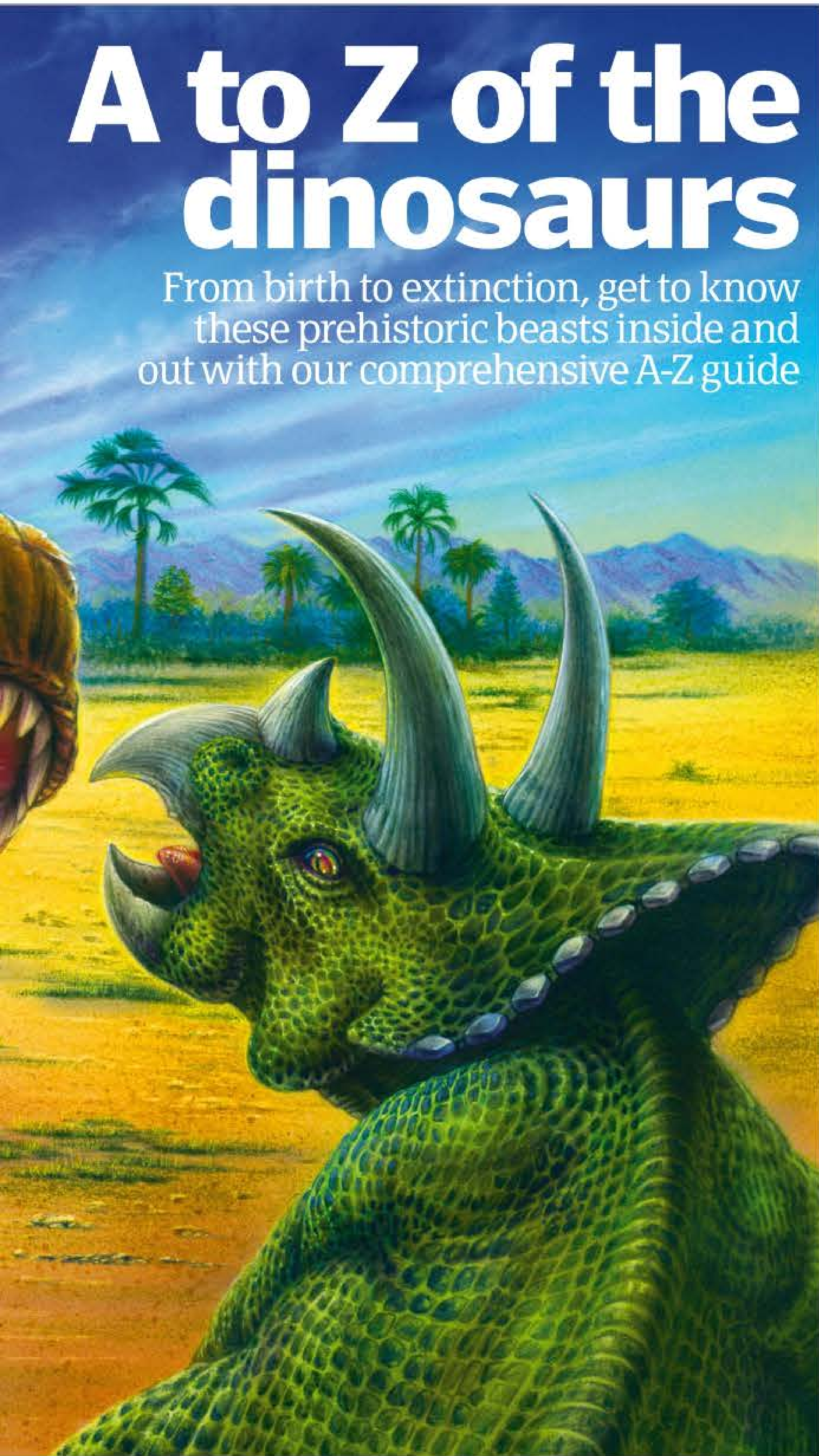
038 Tyrant lizard king



041 Meteor impact

037 Mass extinction

048 Triassic forests



A to Z of the dinosaurs

From birth to extinction, get to know these prehistoric beasts inside and out with our comprehensive A-Z guide

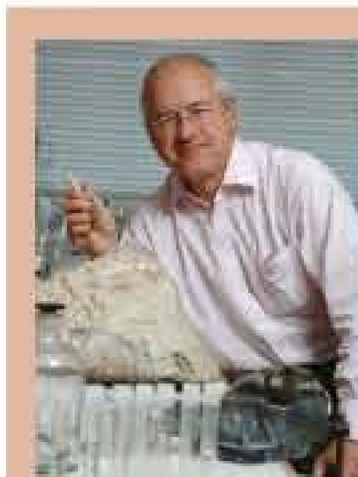
Dinosaurs have long sparked our imagination. From the Ancient Greeks' perception of their remains as evidence of a time when giants ruled Earth, right through to modern man's pursuit of their resurrection – be that in films like *Jurassic Park* or in laboratories via advanced DNA cloning techniques – dinosaurs remain a tantalisingly alien part of our world's history.

They may no longer roam the land like they did millions of years ago, but thanks to their genetic legacy and preserved remains they still remain a very real presence today.

From the fossils lying trapped in the ground through to the descendants flying above our heads, dinosaurs have unique tales to tell.

We take a closer look at this ancient world through an A-Z encyclopedia of all things dinosaur. You'll learn not just about the creatures themselves but the tools and techniques used to study them, and what Earth was like during their reign. This guide truly has it all, so strap yourself in and prepare for one wild, prehistoric ride...

Benton on a fossil dig near Albuquerque, New Mexico



Professor Mike Benton, palaeontologist
Mike Benton is the Professor of Vertebrate Palaeontology at the University of Bristol, UK, and is a world-renowned dinosaur specialist. His areas of expertise include the diversification of life through time, the origin of dinosaurs and the end-Permian mass-extinction event. He can be found working on digs in Russia and China. Meanwhile, he offers words of wisdom throughout our dino guide!

A

Amber & dino DNA

Amber is fossilised tree resin that, due to a chemical change after burial in the ground, turns into a solid. Despite its stable state today, when the majority of the Earth's amber formed, it was far more fluid, which means many little organisms unwittingly became stuck within it – including plant matter and insects. Today these appear frozen within the amber and have been perfectly preserved. While one or two studies in the Nineties claimed to extract DNA from these organic inclusions (as portrayed in), more recent research suggests this isn't possible. Scientists at the University of Manchester using advanced DNA sequencing in 2013 were not even able to find traces of DNA in copal (a precursor to amber) only 10,000 years old, so they're very doubtful that dino DNA could have survived from millions of years ago.

C

Communication in focus

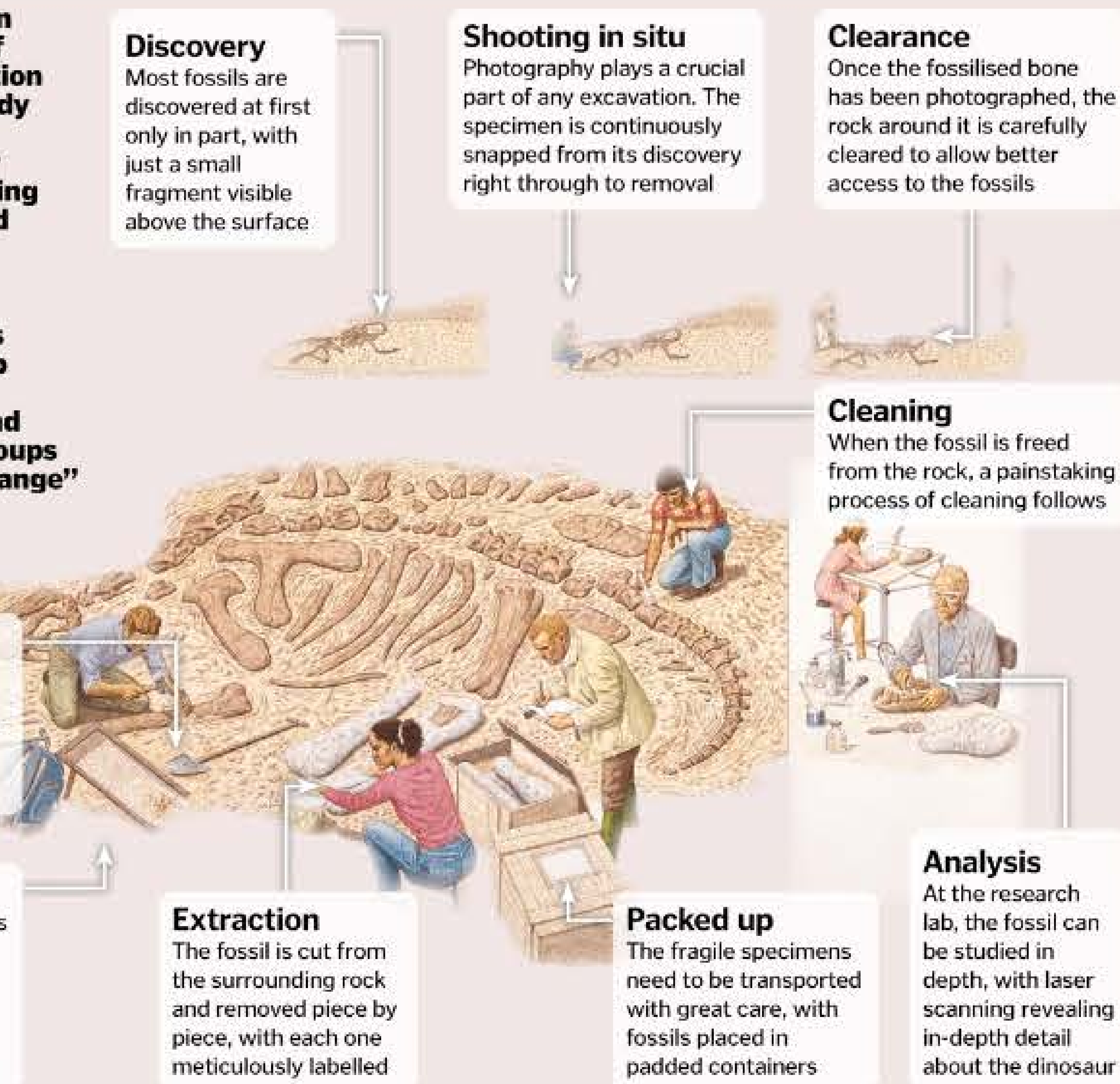
Dinosaurs, much like the many species of animal alive today, communicated in very different ways. From complex dance-like movements to more obvious calls and scent markings, each dino marked their territory, warned of potential predators and relayed information regarding food in its own unique way. One of the most interesting examples comes in the form of the hadrosaurid (above), a duck-billed dinosaur family sporting a distinctive bone crest on their heads. These crests were used as a resonating chamber for projecting their calls. Considering the hadrosaur's modest size and its wide range of predators, the ability to amplify its calls was no doubt a valuable defensive mechanism.

B

"Certain kinds of excavation and study out in the field can be for palaeoecology, trying to reconstruct food webs and modes of locomotion, or they can be about looking at patterns over time, going up metre by metre in rock formations and analysing fossil groups to see how they change"

Bone secrets

Dinosaur bones are one of a palaeontologist's greatest sources of information, supplying data about their age, anatomy, distribution and much more. The bones of dinosaurs can only be found if they went through the process of fossilisation, where the tissue of the creature dissolves and gets replaced with minerals under pressure beneath the ground. Finding and extracting these fossilised bones is a major challenge for palaeontologists, with a carefully planned out dig site essential.



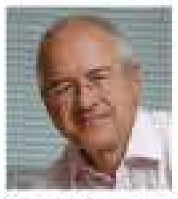
DID YOU KNOW? The London Natural History Museum's Diplodocus is touring the UK in 2018

D
Diplodocus: a dino titan

Of all the dinosaurs that lived on Earth few can truly lay claim to be a terrestrial giant – but the Diplodocus can. Built like a suspension bridge, the Diplodocus measured over 25 metres (82 feet) long – that's longer than five African elephants! It weighed over 12 tons, roughly 170 times more than the average human. It had an incredibly long neck and counterweight tail, the former used to elevate its head into the foliage of trees for food, while the latter was its primary form of defence. With a typical Diplodocus estimated to have lived between 50 and 80 years, it also had one of the longest life spans of any dinosaur from the Jurassic period.

F
Feathered fiends

Since palaeontologists began uncovering dinosaur remains in the 19th century, our depictions of them in the flesh have been largely coloured by a few initial artist impressions, with figures such as Charles Knight often drawing species in inaccurate postures and with factually incorrect sizes, colours and features. Based on current evidence, the lack of feathers on most species is one of the most obvious flaws in these early depictions, with half of all non-avian theropods now thought to have been partly feathered. The main cause for these misassumptions has been the lack of evidence, with feathers and soft tissues rarely preserved like fossilised bone.



"Colour in dinosaur feathers was a topic I think people thought that we would never know the answers to. But we were able to rely on a fair number of fossil feathers that were exceptionally well preserved and deep within their internal structure we could see colour-bearing organelles. So by using some smart observations and techniques we have proved it to be possible"

E
Extinction

Dinosaurs perished some 65 million years ago in what is known as the K-Pg (formerly K-T) extinction event. This cataclysmic event at the Cretaceous-Palaeogene boundary led to 75 per cent of all species on Earth dying off. From the smallest ocean plankton to the largest land beasts, the K-Pg extinction event resulted in devastation at every level of the world's ecosystems, with all non-avian dinosaurs eradicated. The current theory for the catalyst of this global wipeout is an asteroid impact in South America, but the real cause for such widespread carnage was not the impact itself but its knock-on effects. These include plants not being able to photosynthesise due to dust blocking out the Sun plus a series of epic tsunamis and fire storms.

G
Genetic legacy

Today the study of dinosaurs is entering an exciting new age, where we can achieve an unprecedented level of accuracy through cutting-edge analysis. After a T-rex's soft tissue was discovered within a bone sample, we can now study things like proteins, blood vessels and other micro-anatomy to help us determine how individuals lived and died, as well as how dinos evolved.

H
Hunting strategies

Whether dinos hunted and scavenged alone like the T-rex or in large packs like the Deinonychus – the model for the Velociraptor in *Jurassic Park* – carnivorous dinosaurs were no doubt the apex predators on Earth. However, debate rages as to how co-ordinated dinosaur pack hunters were. Since first described in 1969 by palaeontologist John Ostrom, the Deinonychus has been imprinted in the public consciousness as a highly intelligent, synchronised team hunter. However, many modern dino experts disagree with this assumption, believing that while Deinonychus did move and chase prey in groups, they did so with little co-ordination, with each individual simply acting out of self-interest rather than working together like, say, lions.

I

Ichthyosaurus

Although technically not a true 'dinosaur', Ichthyosaurus, or 'fish lizard', filled the same niche in Earth's oceans and was one of the most dominant marine species of the Mesozoic era (252-65.5 Ma) Resembling today's dolphins, Ichthyosaurus measured in at roughly two metres (6.6 feet) in length and was capable of cruising through the water at around 40 kilometres (25 miles) per hour, enabling it to catch fish and squid with ease. The fact that Ichthyosaurus had a very large pair of eyes protected by a pair of bony, structural-supporting rings has led some palaeontologists to believe the species frequently hunted at great depths where pressure was very high.

1 Eyes
Large eyes were protected by rings of bone to keep them intact at great depths.

2 Teeth
The jaws were lined with rows of sharp, conical teeth, primed for shredding soft prey such as squid.

3 Fins
Stunted limb-like fins were used for stability and manoeuvring rather than propulsion.

4 Prey
Fish, squid and marine reptiles were the main food of Ichthyosaurus, but the sharp teeth could crush shellfish as well.

5 Body
Its body was streamlined, with a curved spine and no neck. By undulating its body it could alter its speed and direction.

6 Tail
A top speed of 40km/h (25mph) came courtesy of the bilobed, shark-like tail.

J

Jurassic lark Five factual bloopers from the famous Hollywood films

Timing problems
Jurassic Park portrayed many famous dinosaur species, including T-rex and Triceratops, but most of the animals shown actually lived in the Cretaceous period, not the Jurassic.

Out of proportion
One thing the film's producers definitely need punishing for is the depiction of the park's Velociraptors. Portrayed as being as tall as a man, in reality they barely stood 0.5m (1.6ft) off the ground.

Feather-brained
Another massive omission in *Jurassic Park* was the lack of any feathers. Most dinosaur species, especially sauropods, had some plumage on their bodies.

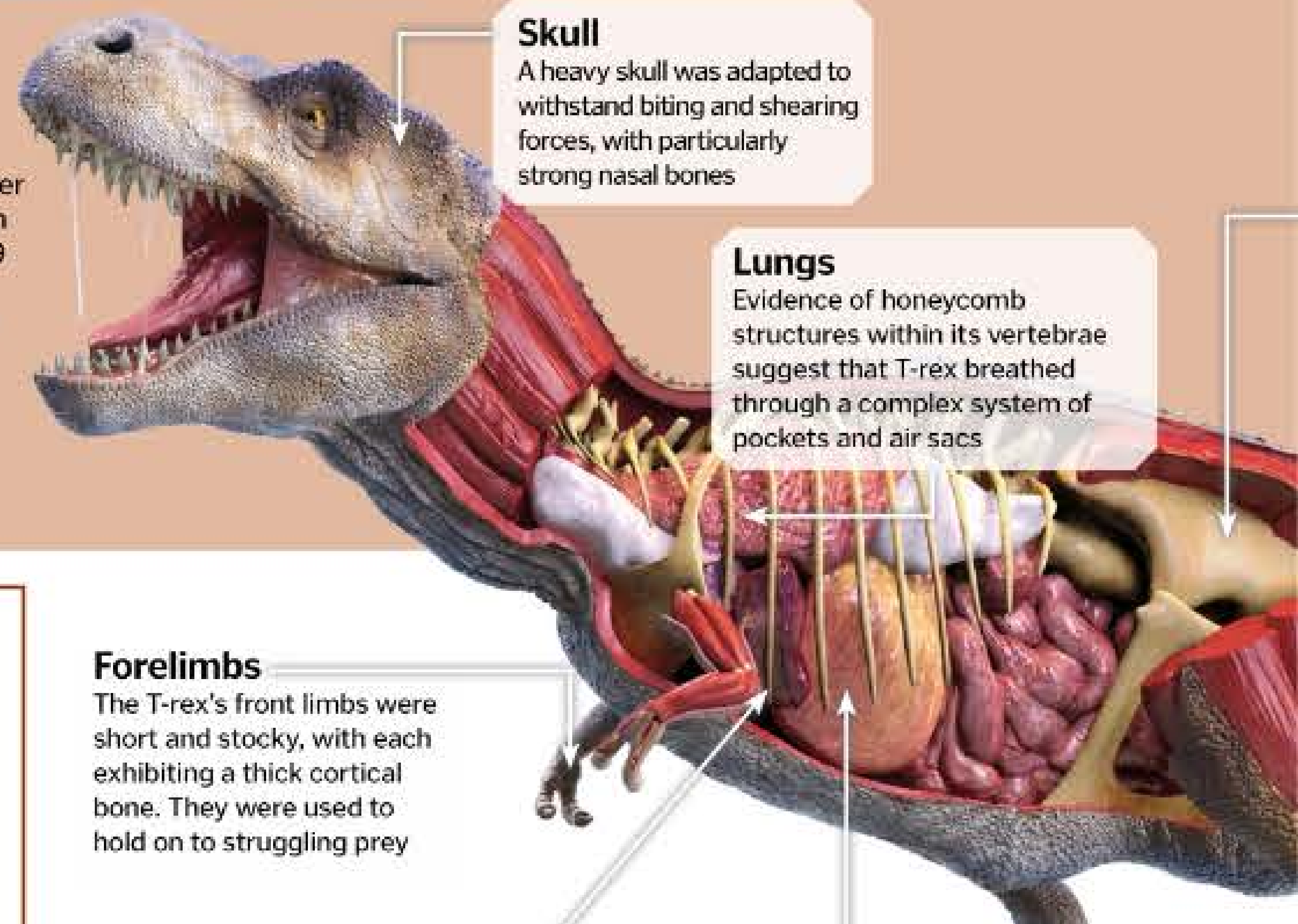
No grudge match
In the third film, the Spinosaurus is shown going toe-to-toe with its supposed arch-nemesis, the T-rex. In reality they never met as they lived on different continents of prehistoric Earth.

Spit on a grave
Another creative addition was Dilophosaurus's ability to spit out venom. However there is no evidence to suggest it could do this; neither did it have a frilled neck.

K

King of the dinosaurs

While not the biggest or smartest, the Tyrannosaurus rex was no doubt the closest to a king the dinosaurs ever had. A colossal bipedal carnivore, the T-rex measured in at over four metres (13 feet) tall and over 12 metres (39 feet) long, weighing over seven tons. It was no slow-poke either, with computer models estimating that the dino was capable of hitting a top speed of around 29 kilometres (18 miles) per hour chasing prey. When it caught up it could quickly dispatch them with a single bite that had a force of three tonnes – the equivalent weight of a fully grown African elephant. Yikes!



Skull
A heavy skull was adapted to withstand biting and shearing forces, with particularly strong nasal bones

Lungs
Evidence of honeycomb structures within its vertebrae suggest that T-rex breathed through a complex system of pockets and air sacs

Forelimbs
The T-rex's front limbs were short and stocky, with each exhibiting a thick cortical bone. They were used to hold on to struggling prey

Heart
With a body bigger than a bus, the T-rex needed a huge pump to transport blood at adequate pressure. Current estimates suggest its heart was over 100 times bigger than a human's

Stomach
The T-rex had a hardy stomach due to its high-meat diet and the fact that it scavenged frequently from long-dead carcasses. Analysed T-rex dung has revealed many fragments of bone

L

Lufeng: a fossil treasure trove

One of the most prolific dinosaur hotspots in the world is Lufeng in Yunnan Province, China. Since 1938, 33 species, each with its own complete fossil, have been found there. Some of the finds have been record-breaking, with many of the vertebrate fossils uncovered the oldest on record – the Lufengosaurus fossil (right) dates from 190 million years ago. Lufengosaurus was a genus of prosauropod that lived during the Early Jurassic period. Excavated finds can be seen at the Lufeng Dinosaur Museum.

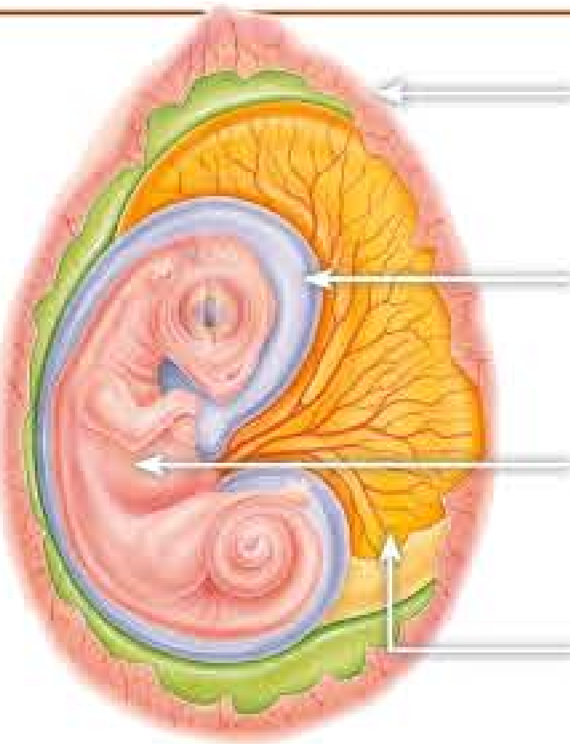
Mesozoic world

Beginning 252.2 million years ago and coming to a close about 65 million years ago, encompassing a colossal stretch of time that includes the Triassic, Jurassic and Cretaceous periods, the Mesozoic era truly defined the age of dinosaurs. All the famous species you can think of lived within it.

The Mesozoic was generally warm with a significantly smaller temperature differential between the equatorial and polar regions – ideal conditions for the emergence and proliferation of flora and fauna. Not only was the Mesozoic famous for its domination by dinosaurs, but also for being the time period where the ancestors of today's major plant and animal groups emerged.

Nesting & dinosaur eggs

Dinos organised their nests, laying their eggs in patterns suggesting complex social behaviours. Palaeontologists have identified two main types of egg-laying strategies – clutches and linear patterns – further divided by the shape of the nest and distribution of eggs. For example, the ornithopod Maiasaura nests generally consisted of bowl-shaped excavations roughly two metres (6.6 feet) wide and 0.8 metres (2.6 feet) deep, the opening covered by loose vegetation. Each nest was spaced roughly seven metres (22 feet) apart and was used by their offspring until they were over a metre (3.3 feet) long.



Outer shell
Dinosaur eggs were elongated and had hard, brittle shells. Some of the largest found to date were 0.6m (2ft) long

Amniotic membrane
Encompassing the dinosaur was a thin membrane, helping keep the embryo hydrated during development

Embryo
At the centre lay the dinosaur embryo that, depending on the species, could take weeks or months to hatch

Yolk sac
This contained proteins and fat which served as food for the baby dino

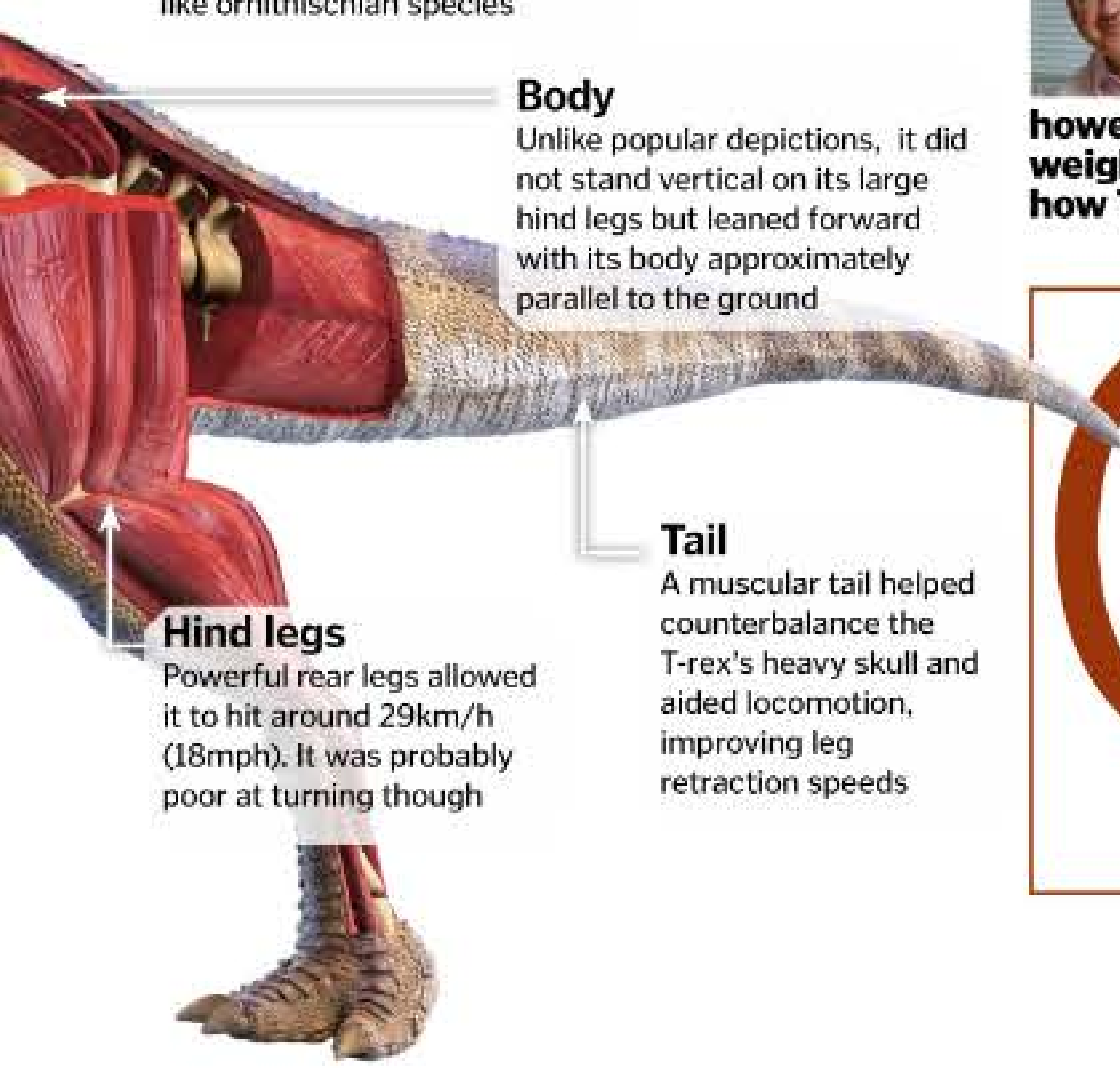
Palaeontology: key players

Most of our current knowledge of the dinosaur kingdom comes courtesy of palaeontologists, who dedicate their lives to uncovering the secrets of their prehistoric kingdom. From the earliest dinosaur hunters such as Othniel Marsh (pictured left), who discovered and named the Allosaurus, Stegosaurus and Triceratops, to 20th-century scientists who revolutionised our understanding of the dinosaurs' legacy, such as John Ostrom who gained fame for his suggestion that birds were modern-day descendants, palaeontologists have helped provide tantalising glimpses of the prehistoric world.

One of the more contemporary palaeontologists who has helped introduce dinosaurs to the general public is Dr Philip J Currie. He is also a museum curator who helped found the prestigious Royal Tyrrell Museum of Palaeontology in Alberta, Canada.

Pelvis
The T-rex was a saurischian dinosaur, meaning it had a lizard hip arrangement. Its pubis bone pointed forward and down rather than backward and down like ornithischian species

"Weighing something like five tons yet walking bipedally makes the T-rex incredibly interesting, as it pushes the absolute limits of what is possible. I mean, you look at an elephant and think, 'Wow, that's amazing', however, an elephant has to walk on four legs and weighs roughly the same amount, so understanding how T-rex functioned is a fascinating area of research"



Body
Unlike popular depictions, it did not stand vertical on its large hind legs but leaned forward with its body approximately parallel to the ground

Tail
A muscular tail helped counterbalance the T-rex's heavy skull and aided locomotion, improving leg retraction speeds

Hind legs
Powerful rear legs allowed it to hit around 29km/h (18mph). It was probably poor at turning though

Queensland

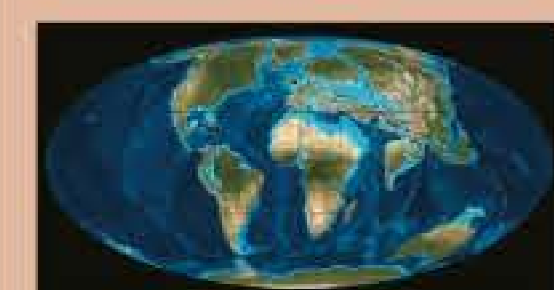
If you were to visit Queensland's more remote regions, you may very well find yourself standing face to face with one of many 100-million-year-old beasts. That's because Queensland's outback was once part of the Great Inland Sea, a huge swampy inland ocean that existed in the age of the dinosaurs. As such, hundreds of fossils have been excavated from this region and there is even an established 'Australian Dinosaur Trail' that tourists can follow.

Oceans & continents

1 Triassic
At the beginning of the Mesozoic era in the Early Triassic period, all the land on Earth was joined together into the supercontinent of Pangaea, itself surrounded by the superocean Panthalassa.

2 Jurassic
As the Mesozoic progressed and the Triassic made way for the Jurassic period, plate tectonics split Pangaea into two mega-continents: Gondwana and Laurasia, separated by the Tethys Sea.

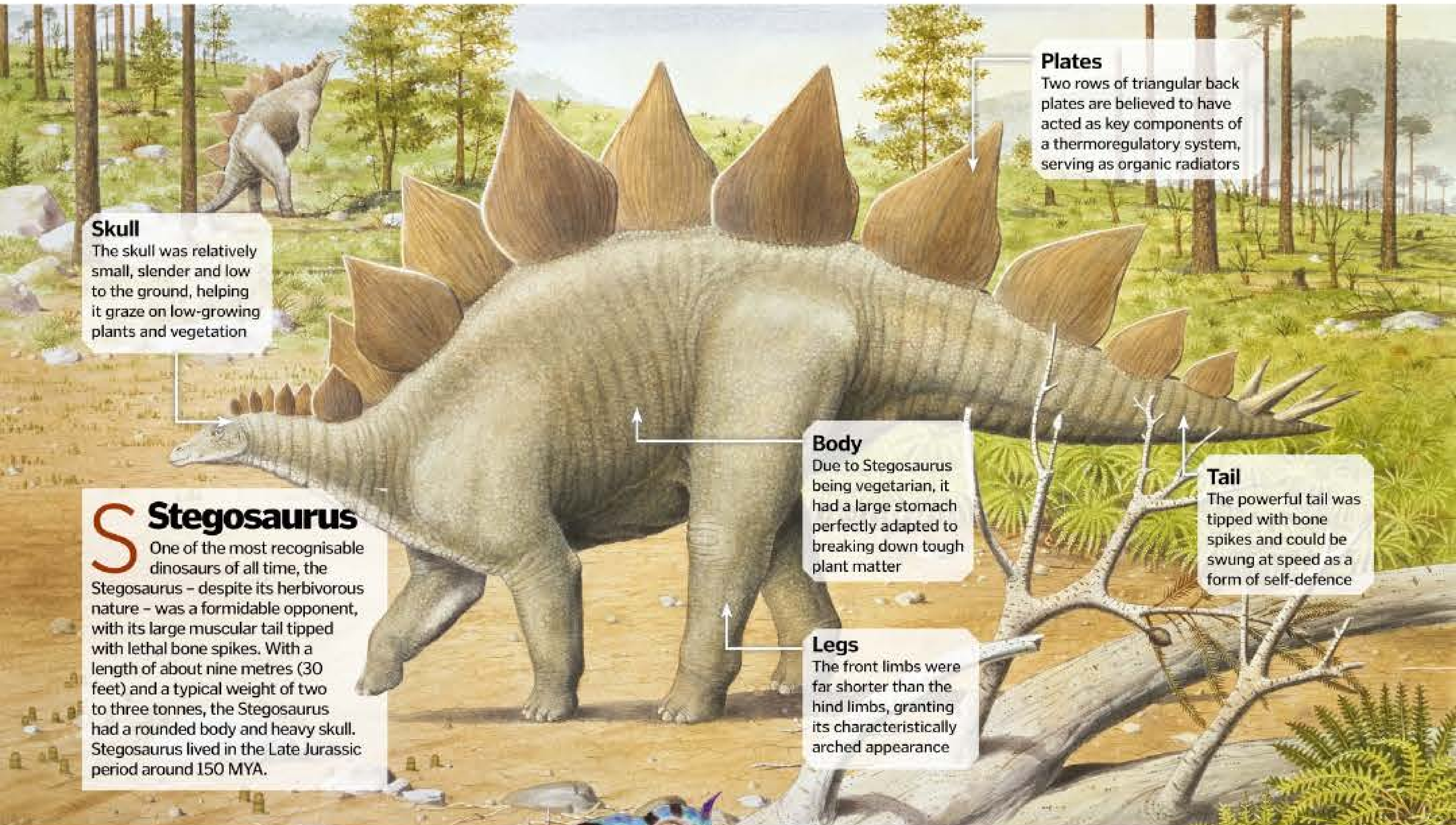
3 Cretaceous
As the Mesozoic came to a close, Gondwana and Laurasia had split into many of the continents we know today, including North and South America and Antarctica.



4 Palaeogene
In the Palaeogene period – immediately following the K-Pg extinction – those continents continued to move to their current positions.

R — Relatives in the modern world

Massive scientific effort has been put into identifying which creatures today can trace their roots back to these prehistoric beasts. One of the best examples of this was the hunt for the nearest living relative of the once-mighty T-rex, undertaken by a research team at the North Carolina State University in 2007. To go about this the researchers sequenced proteins from a 68-million-year-old T-rex tissue sample and, much to their surprise, discovered that the king of the dinosaurs' molecules showed remarkable similarity to the common chicken and that its collagen makeup was almost identical. So, at least for the time being, the humble chicken is the rightful ruler of the Earth...



S — Stegosaurus

One of the most recognisable dinosaurs of all time, the Stegosaurus – despite its herbivorous nature – was a formidable opponent, with its large muscular tail tipped with lethal bone spikes. With a length of about nine metres (30 feet) and a typical weight of two to three tonnes, the Stegosaurus had a rounded body and heavy skull. Stegosaurus lived in the Late Jurassic period around 150 MYA.

T — Tall tails

You'll struggle to find a dinosaur without a tail. This is because the majority of dinosaurs used their tails for two important roles: the first being balance and the second being self-defence. Large animals like the T-rex and Diplodocus, thanks to their skulls or necks, were very top-heavy. They needed long and heavy tails to counterbalance this, especially when running. Smaller creatures such as Ankylosaurus (inset, left) used its tail when under attack, evolving a large bony club at the end which could bludgeon assailants.

U — Unenlagia: half bird, half dinosaur

One of the most telling links between dinosaurs and birds is the Unenlagia, a genus of theropod dinosaur from the Late Cretaceous that in almost all aspects, aside from flight, resembles a modern bird. It was discovered in 1997 and to date two species have been confirmed – U comahuensis and U paynemili – both of which share an almost identical pelvic structure to the early bird species Archaeopteryx.

V — Velociraptors debunked

Due to their appearance in the *Jurassic Park* films, the Velociraptor is easily one of the most recognisable of all species. Importantly though, this image of the Velociraptor is way off the mark in terms of reality.

In contrast to the movie monster, research evidence suggests that the Velociraptor was actually a feathered dinosaur under 0.6 metres (two feet) in length, with colourful plumage used in mating rituals and visual displays. The species also had hollow bones, much like birds, and built large nests to protect their offspring.

The Velociraptor did impress in ground speed, with it capable of hitting 39 kilometres (24 miles) per hour at top speed and boasting amazing agility, being able to change direction incredibly quickly. It used this speed to chase down prey, which largely consisted of small to medium-sized herbivores such as Protoceratops, and then kill them with its nine-centimetre (3.5-inch) retractable claws and sharp teeth.

New research suggests that, while sociable compared with other carnivores, raptors were not apex pack hunters, with co-operative kills possible but infrequent.

DID YOU KNOW? *Iguanodon's thumb spike was originally thought to be a horn on the end of its nose*

Winged wonders

While not technically dinosaurs, pterosaurs were very much the winged wonders of the dinosaur era. Flying reptiles that evolved throughout the Late Triassic and dominated the skies until the Late Cretaceous, pterosaurs were the earliest vertebrates currently known to have evolved powered flight. Pterosaurs are not related to modern-day birds or bats, with the many species evolving earlier and separately.

The genus Pterodactylus was one of the most notable, with the species Pterodactylus antiquus one of the most impressive, with a toothed beak, large eyes and clawed wings. In terms of wingspan P antiquus could extend its wings up to a metre (3.3 feet) and had a long, narrow skull packed with dozens of sharp, pointed teeth. It used these to snap up fish and smaller reptiles.

"Microraptor was a small, four-winged dinosaur… very close to the origin of birds. Its remains show it had wings on its arms and legs. It couldn't fly properly, but used its wings to glide. This shows the origin of flight in birds and their ancestors was much more complex than expected"

❶ Beak

Up to 90 teeth in the long beak intermeshed when the jaw was closed, and were perfect for grabbing fast prey.

❷ Wings

A wingspan of around 1m (3.3ft) was typical for Pterodactylus, with the wings structured in a way that indicates it would have flown like an albatross.

❸ Body

Not as large as depicted in fiction, Pterodactylus was very lightly built with hollow bones and a long neck.

❹ Limbs

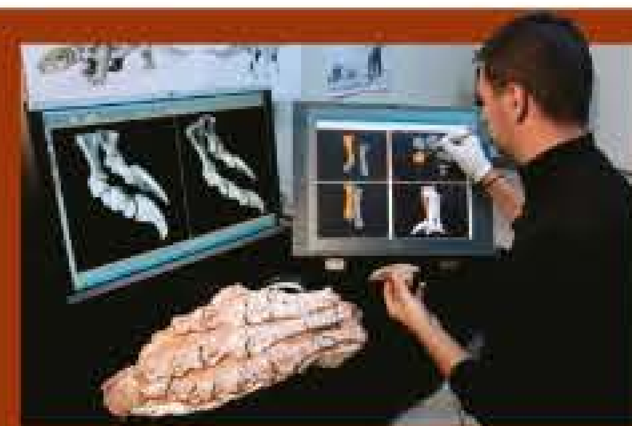
Pterosaurs evolved a unique pteroid bone on the wrists of their forearms, used to support the forward wing membrane located between the wrist and shoulder.

❺ Tail

Unlike some other pterosaurs, Pterodactylus had a relatively short, stubby tail.

X-raying prehistoric remains

X-ray scanners have become incredibly useful and important tools in the world of palaeontology as they can reveal many fossils and features that otherwise would remain hidden. For example, in November 2013, researchers in Germany used an X-ray machine to unveil the detailed structure of a fossil trapped within a plaster cast, all without ever having to break it open and risking damage to the specimen. What's more, the researchers then made use of a 3D printer to re-create the X-ray scans in solid form, allowing palaeontologists to pick up and handle a cast of the fossil as fine and detailed as the real thing. Modern technology is set to further our understanding of dinosaurs by no bounds.



Yucatán impact

The colossal Chicxulub crater in the Yucatán Peninsula, Mexico, since its discovery in the Seventies, has heavily hinted as to how 75 per cent of all life on Earth was eradicated around 65.5 million years ago. The crater indicates that a space rock – probably an asteroid – at least ten kilometres (six miles) across impacted Earth. As a result of the extensive damage caused directly by the collision and consequently by tsunamis, dust storms and volcanism, it caused a total collapse in the world's ecosystems, with all non-avian dinosaurs at the top of the death list. Despite being challenged repeatedly, the impact's link to the K-Pg mass extinction has recently been reaffirmed with even more detail, with a research team linking the two events in time to within 11,000 years. That said, the researchers also highlighted that various precursory phenomena, such as dramatic climate swings, also contributed to the end of the dinosaurs post-impact.

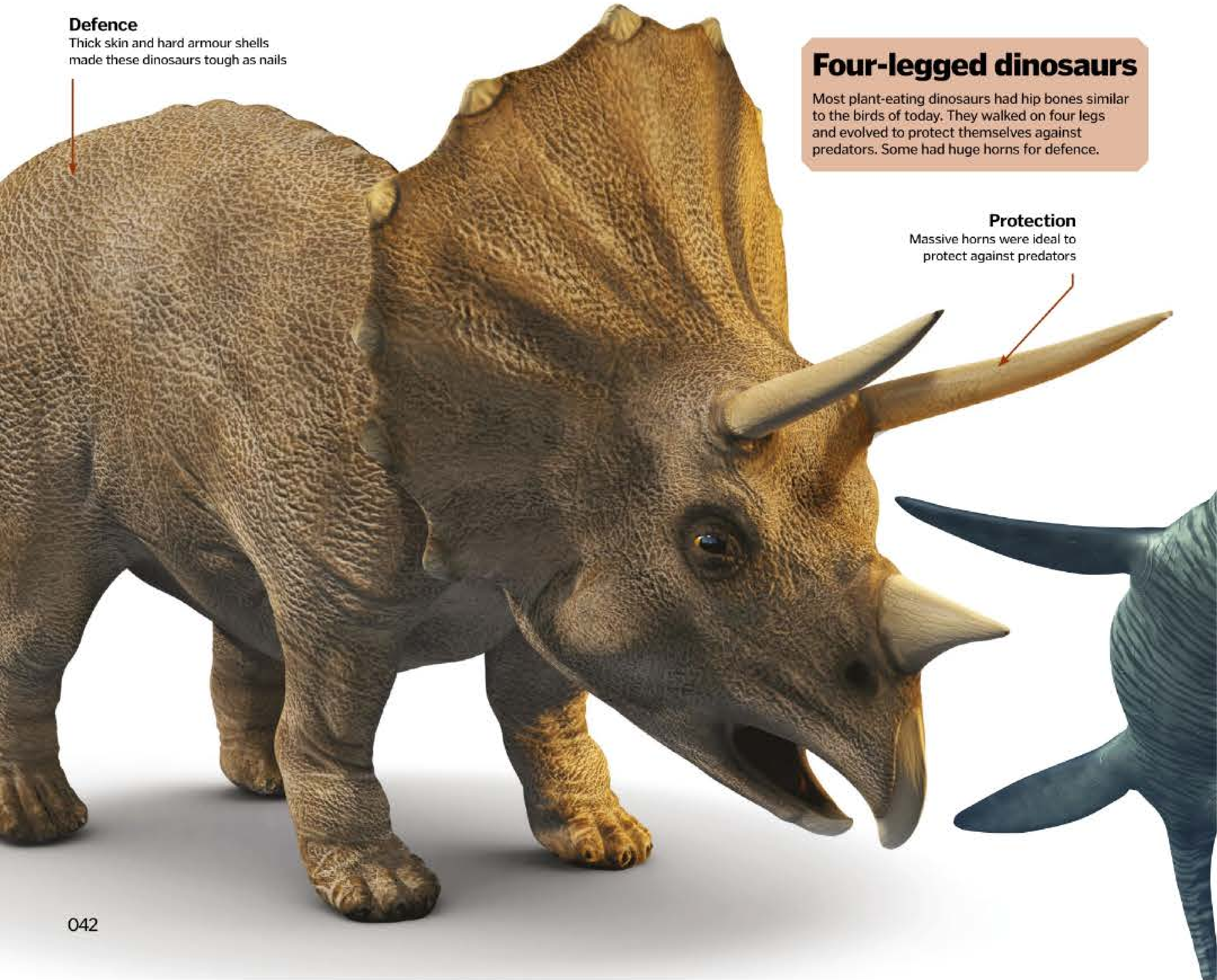
Zalmoxes sized up

Zalmoxes, a genus of herbivorous dinosaur from the Late Cretaceous period, is believed by some to be one of the earliest examples of insular dwarfism – a condition whereby a species undergoes a continuous reduction in size to better suit its environment, shrinking over several generations. Fossils from at least two species of Zalmoxes have been found in central Europe and one of its closest ancestors is thought to be the much larger Iguanodon.

What was a dinosaur?

Dinosaurs were a reptile that first appeared over 230 million years ago. They lived on Earth longer than any other creature in history

Dinosaurs dominated the Earth for over 160 million years, often as the apex predators of their particular environments. Although fossilised dinosaur remains have been discovered throughout human history (early discoveries probably being the origins of mythical creatures such as dragons and hydras), dinosaurs were only described scientifically in the early nineteenth century. It was British palaeontologist Sir Richard Owen who coined the taxon Dinosauria in 1842. The word dinosaur means "terrible lizard", but the term is somewhat misleading, as dinosaurs are not lizards but are part of a separate group of reptiles altogether. Dinosaurs are a diverse group that began life on the super-continent of Pangaea. As continental shift progressed and Pangaea broke up into smaller landmasses, dinosaurs became strongly diversified. It's a wonder that Triceratops and T-rex share a common ancestor.

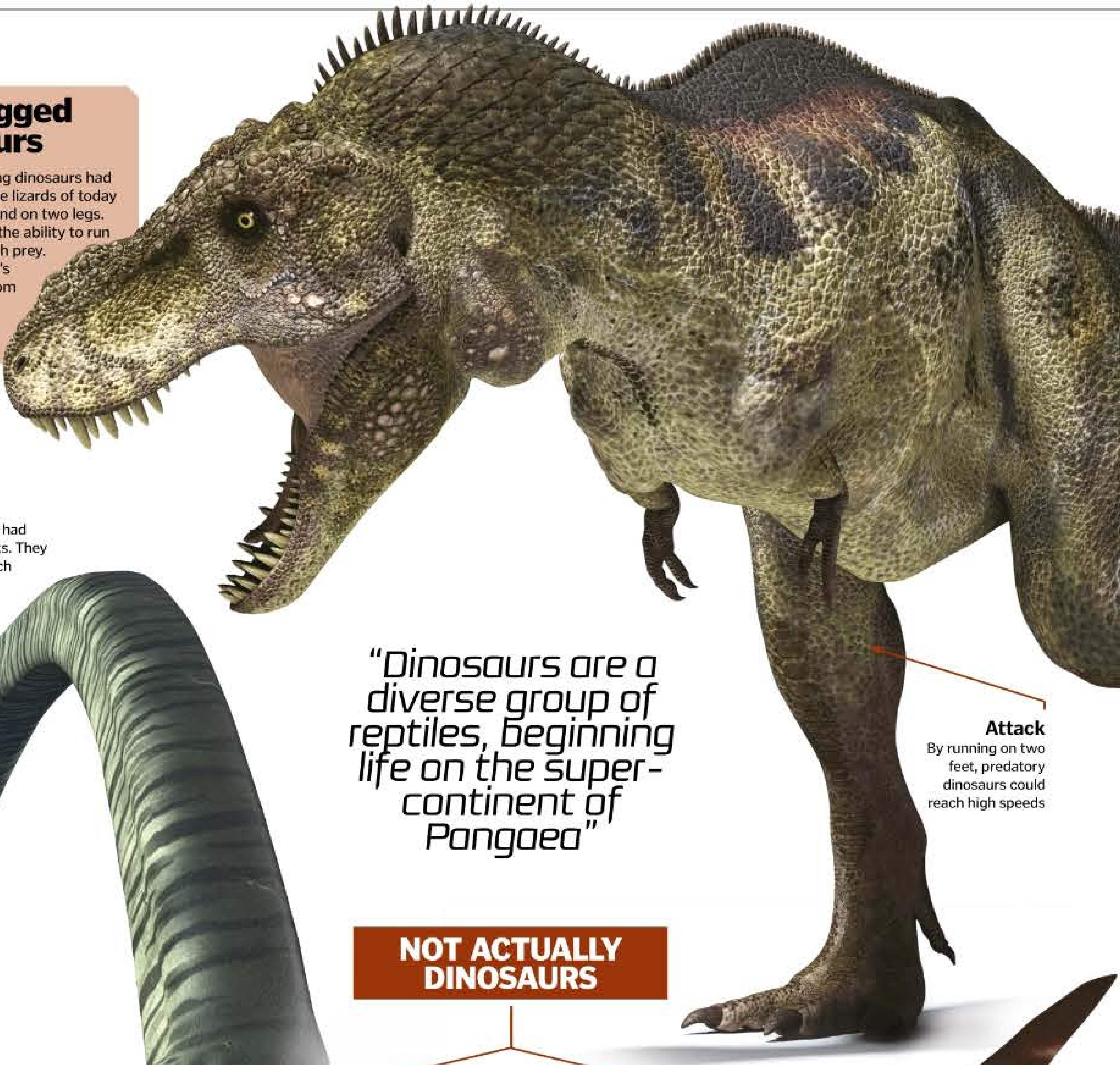


Four-legged dinosaurs

Most plant-eating dinosaurs had hip bones similar to the birds of today. They walked on four legs and evolved to protect themselves against predators. Some had huge horns for defence.

Two-legged dinosaurs

Most meat-eating dinosaurs had hip bones like the lizards of today and moved around on two legs. This gave them the ability to run very fast to catch prey. Strangely, today's birds evolved from lizard-hipped dinosaurs.



Attack
By running on two feet, predatory dinosaurs could reach high speeds

"Dinosaurs are a diverse group of reptiles, beginning life on the super-continent of Pangaea"

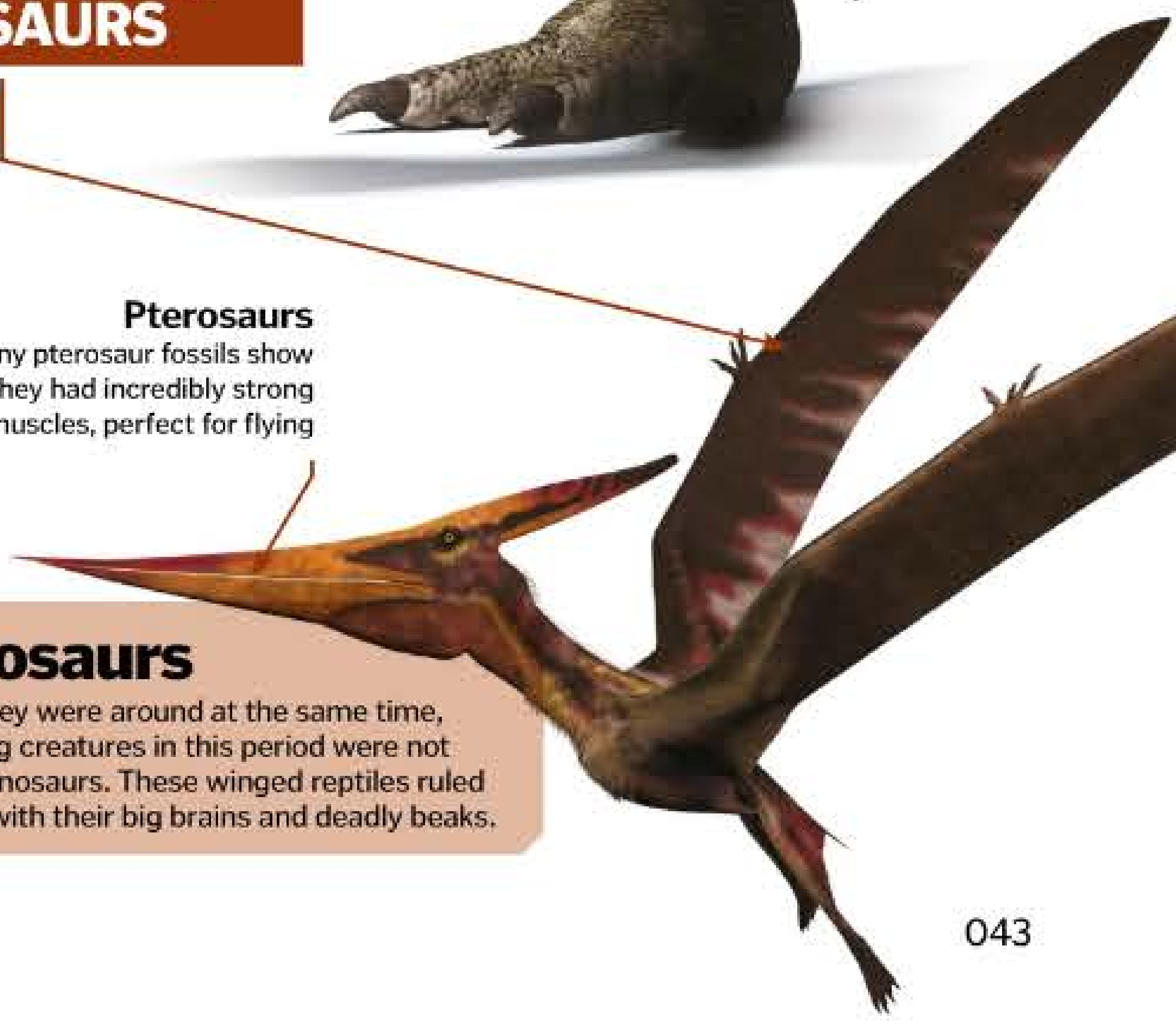
Plesiosaurs
Some plesiosaurs had long, flexible necks. They used these to catch nimble fish

NOT ACTUALLY DINOSAURS

Swimming reptiles

The oceans of the world were once ruled by ichthyosaurs, plesiosaurs and mosasaurs, not dinosaurs. Many of these underwater animals looked a lot like modern-day fish. They were perfectly adapted for life in the sea and fossils show that they may have given birth to live young.

Pterosaurs
Many pterosaur fossils show they had incredibly strong muscles, perfect for flying



Pterosaurs

Though they were around at the same time, most flying creatures in this period were not actually dinosaurs. These winged reptiles ruled the skies with their big brains and deadly beaks.

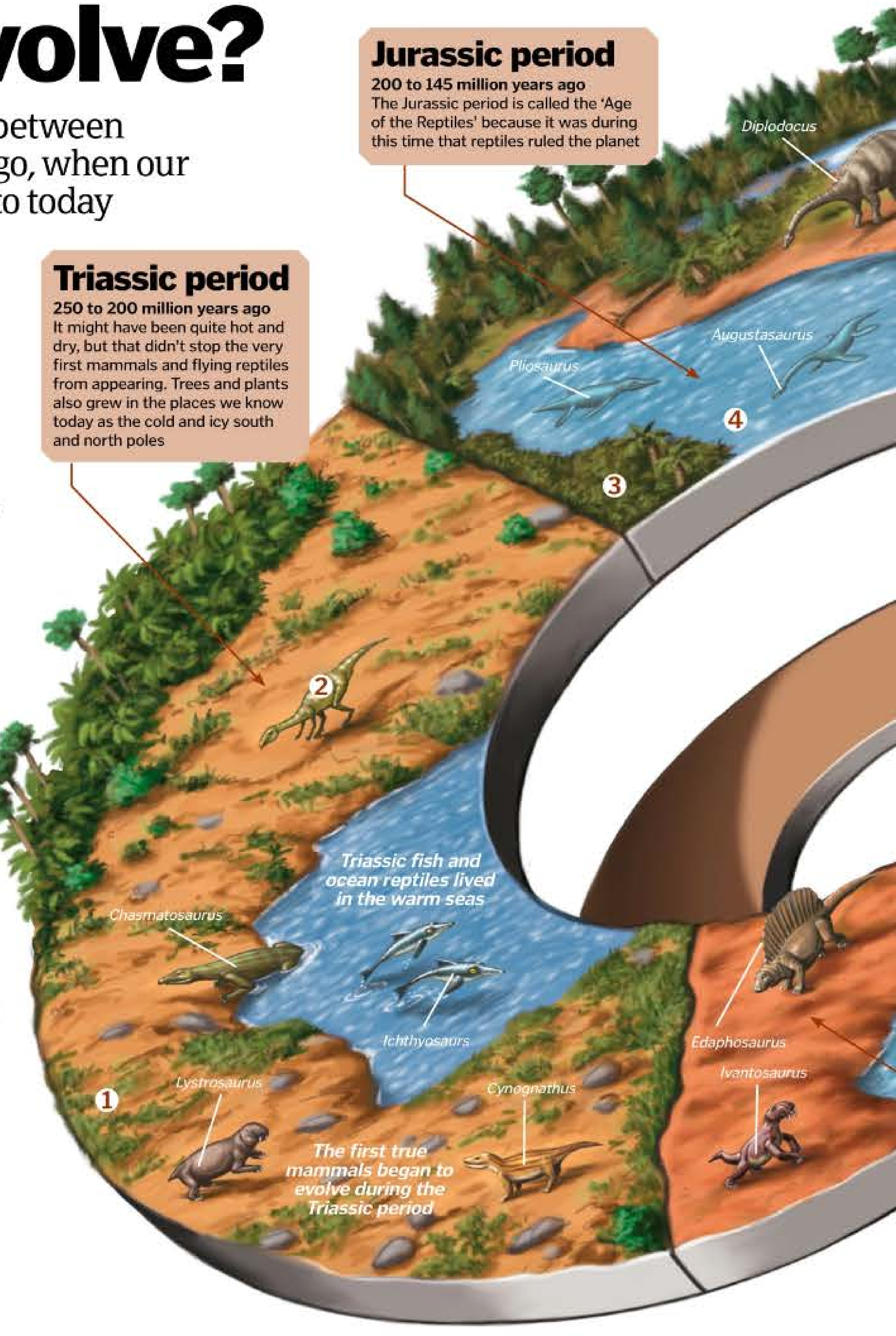
How did the dinosaurs' world evolve?

Dinosaurs roamed Earth between 230 and 65 million years ago, when our planet was very different to today

The ultra-dry climates of the Permian era, and the subsequent destruction of the ancient coal swamps that were home to a great many Carboniferous plants, meant that the Mesozoic (or 'middle life') era signalled something of a recovery period in Earth's history. Comprising the Triassic, Jurassic and Cretaceous periods, the Mesozoic era was less dry but was still swathed in high global temperatures, and the now-empty ecosystems on the land were soon taken over by evolving mammals and dinosaurs. Meanwhile, beneath the oceans, new corals appeared and various sea urchins began to diversify and thrive, having been almost driven to the point of extinction at the end of the Permian era.

Some estimates put some of the more tropical temperatures during the start of the Triassic period (at the beginning of the Mesozoic era) as high as 38°C (100°F), and at this point the world's land masses were still combined in one large supercontinent called Pangaea. During the Triassic period, Pangaea gave rise to climatic zonation, with some areas becoming extremely dry and others experiencing monsoon-like conditions. As a consequence of this climatic zonation, plants began to separate into northern and southern realms.

By the time of the Jurassic period, global temperatures had dropped to around 30°C (86°F) and Pangaea had separated into northern and southern parts. The oceans as we know them today really started to take shape during the Cretaceous period – so-called because of the large chalk content in the shallow seas as a result of the build up of algae skeletons. Following the major extinctions at the end of the Cretaceous period, mammals – which were previously small and insignificant compared to the dinosaurs – were now able to exploit many of the vacant ecosystems and gradually come to dominate the planet.



DID YOU KNOW? Lots of dinosaurs couldn't survive the 60°C heat of the Triassic period

Cretaceous period

145 to 66 million years ago
Sea levels were high during the warm Cretaceous period. Dinosaurs ruled the land, while other types of creatures swam the seas

1 High temperatures
It might have been very hot, but some places had rain

2 The first dinosaurs
Staurikosaurus is one of the very first known dinosaurs

3 Flora
Lush jungles covered much of the land

4 Continents
Around the world, land moved to make more coastlines

5 Predators
Very large land predators like Allosaurus preyed on other animals

6 T-rex
Tyrannosaurus rex lived during the Cretaceous period

7 Sharks
Sharks were common in the seas

8 Cooling down
The Cretaceous period was cooler than earlier periods

9 Mammals
The Tertiary period was called the 'Age of the Mammals'

10 Palm trees
Palm trees grew as far north as Greenland before the middle and end of the Tertiary period

Tertiary

66 to 2.5 million years ago
The dinosaurs had been killed by a great asteroid by this time. In their place, other animals like the saber-toothed cat lived

Permian period

299 to 250 million years ago
It was extremely hot during this time. While there were oceans, the land was very much like a desert. Only reptiles would be able to thrive in this environment

Where did dinosaurs live?

Dinosaurs lived all over the world, from dry, dusty deserts to wet, sweaty swamps. Explore five different habitats that dinosaurs called home…

When dinosaurs first inhabited the Earth back in the Triassic Period (250-200 million years ago), the land they existed on was considerably different to what we know today. All continents formed a single landmass called Pangaea and the climate was hot and dry, causing much of the land to be covered by deserts – which is where dinosaurs first evolved. A series of earthquakes and volcanic eruptions caused Pangaea to split, and many of the dinosaurs became extinct. This led to the Jurassic period and a cooler climate, out of which dense, green jungles took shape – the habitat for different species of dinosaur. Read on to discover which types of dinosaur flourished in each of the different environments.

First dinosaurs

The weather of the Triassic period helped dinosaurs to develop. Their bodies were much better suited to hot and dry conditions compared to mammals

Plants

Only plants that could live without lots of water survived in these areas. There wasn't much for herbivores to eat

DID YOU KNOW? *The extinction event that killed the dinosaurs is one of five major events to have changed the Earth*

Triassic desert

250 to 200 million years ago

Dinosaurs first appeared during the Triassic period. Earth was hot, dry and covered in deserts

Throughout the Mesozoic era, which comprised the Triassic, Jurassic and Cretaceous periods, much was changing on and in the Earth's lands and seas.

The Triassic period was a time of recovery after the devastation, in terms of the fauna and flora, that brought to a close the Permian period. The high global temperatures and the empty ecosystems on the land meant that dinosaurs and mammals evolved during the Triassic period, while the oceans saw sea urchins begin to diversify, having been driven almost to the point of extinction at the end of the Permian period.

Global warming in the early Triassic period produced one of the hottest periods in Earth's history. The resulting deserts were home to a variety of dinosaurs, such as the Euparkeria. Fossil finds in what is now the Karoo Desert of South Africa indicate that these carnivorous creatures were blessed with speed and agility thanks to longer back legs that allowed them to stand upright. An enlarged sinus cavity also suggests they had a fine sense of smell, which would have been ideal for sniffing out prey in its open desert surrounds.

Triassic forest

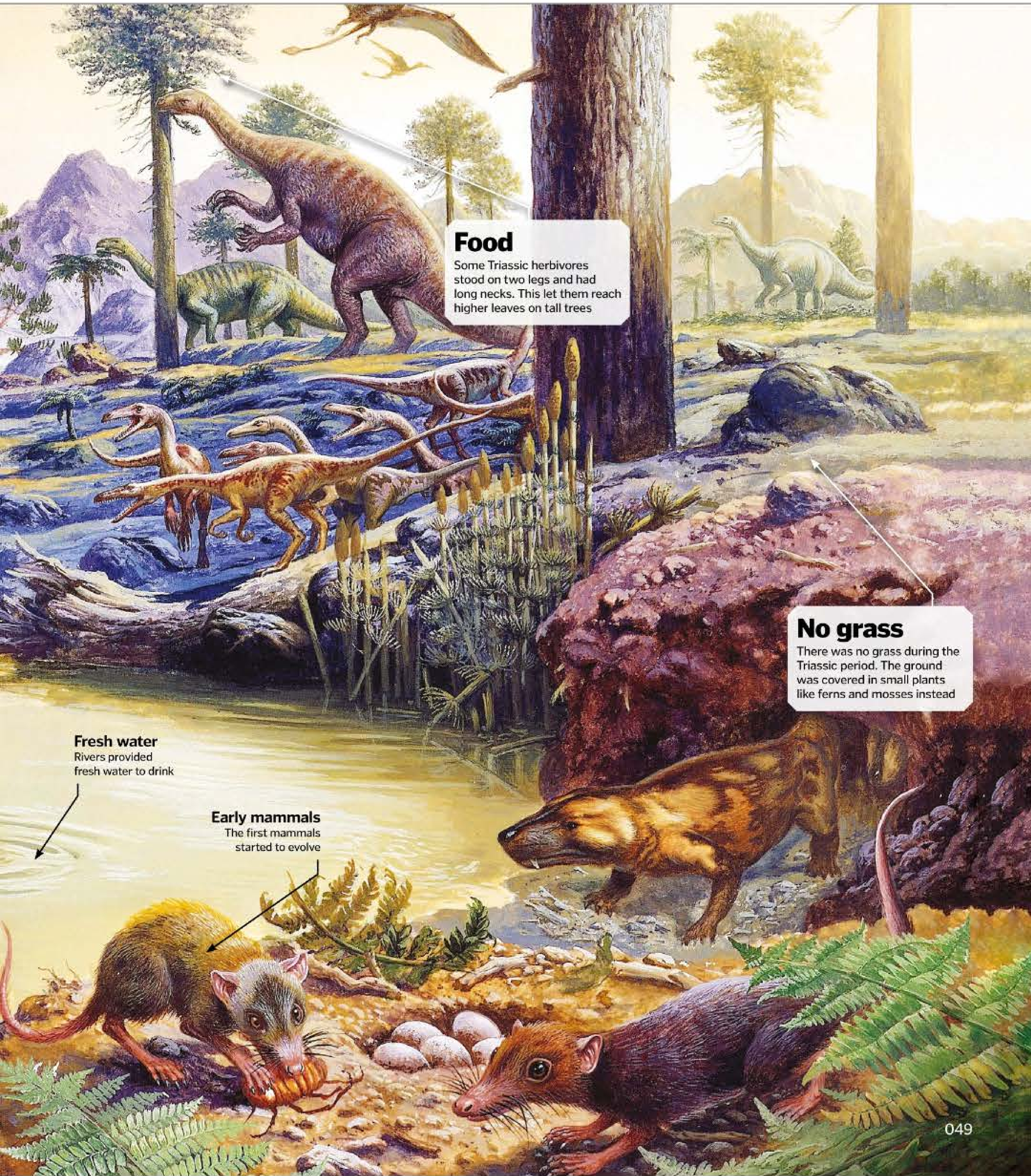
250 to 200 million years ago

The weather was milder at the north and south poles. It was drier, so large forests grew

The presence of coal deposits in the high northern and southern latitudes suggests that these regions were much wetter than the desert-like lower latitudes, so dense, forest-like vegetation was able to grow.

These jungles were home to Rauisuchians, such as the Effigia, and Sauropodomorphs, such as the Plateosaurus, whose long neck and weight-bearing bone structure allowed it to stand upright, which in turn enabled it to feed off plants that were out of reach of other herbivorous dinosaurs.

During the Triassic period, the oceans and continents were starting to change. The land mass of the supercontinent Pangaea was at its largest due to lower sea levels and it had started to move northwards and rotate anti-clockwise, ultimately breaking up to give the Earth a slightly more familiar look. Fossils from the mid-to-late Triassic period indicate that the seas and oceans housed a wide range of marine-based reptiles and ammonites that began to thrive in this period.



Food
Some Triassic herbivores stood on two legs and had long necks. This let them reach higher leaves on tall trees
No grass
There was no grass during the Triassic period. The ground was covered in small plants like ferns and mosses instead
Fresh water
Rivers provided fresh water to drink
Early mammals
The first mammals started to evolve

Jurassic swamp

200 to 145 million years ago

Sea levels were higher during the Jurassic period. Some land got flooded, which created muddy swamps

During the late Jurassic period, the Earth's temperatures had cooled to around 30°C (86°F), declining still further later on in the period, and the Earth began to experience seasonality, with extremely hot summers and unbearably cold winters. Nevertheless, the Jurassic period is when life on Earth thrived, with large dinosaurs roaming the land, huge reptiles dominating the seas and winged reptiles ruling the skies. The oceans were teeming with new predators, including ammonites, belemnites and a range of shell-crushing fish.

One of the most formidable predators of this period was the Allosaurus. With a large skull full to the back with sharp, serrated teeth and three large claws on either hand that may have been used to grip onto its prey, many believe that the Allosaurus hunted stegosaurs, ornithopods and sauropods – creatures that devoured the plants native to the planet's swamps. Stegosaurus is perhaps the best-known stegosaur and was so-called because of the strange, diamond-shaped plates running down its back (Stegosaurus means 'plated lizard'). While many assume that these plates were for defence, the two pairs of long spikes that projected from the tip of the tail were much more likely for this purpose, rendering the plates little more than fancy decorations.


Weather
Regular rainy seasons kept the soil damp. This watered ferns and other small ground plants that herbivores could consume
Continents moving
As Pangaea split up, the new continents had different habitats like swamps. Animals evolved quickly to survive in these new areas

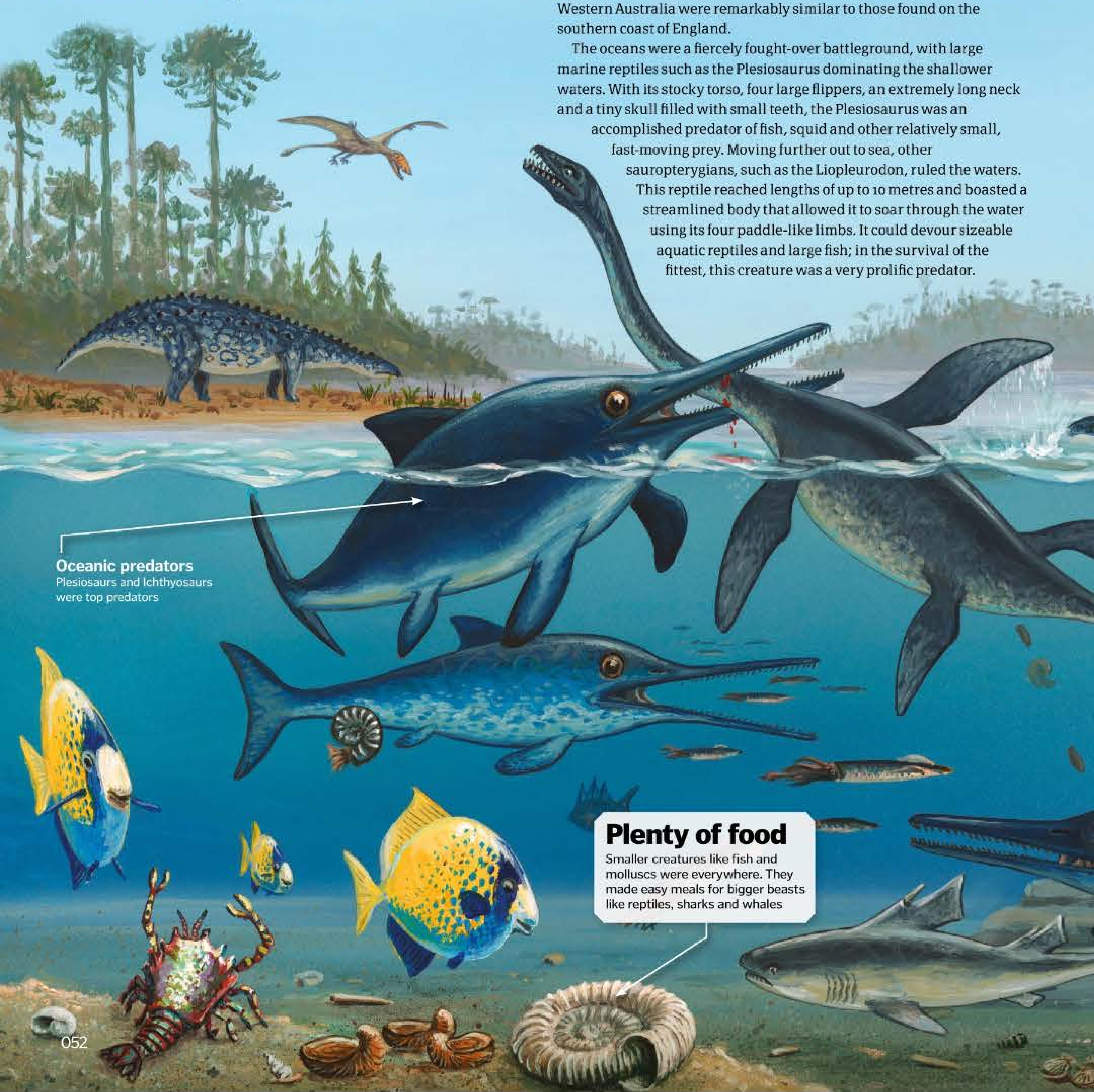
Jurassic ocean

200 to 145 million years ago

Reptiles didn't just live on land. Massive prehistoric monsters ruled the Jurassic oceans as well

Plate movement continued to reshape the continents and widen the oceans during the Jurassic period. The separation of the northern and southern parts of the Pangaea supercontinent continued into the Jurassic period, making the Tethys Ocean considerably larger. This ran in an east-west direction, which had a significant effect on the ocean flora and fauna. As such, fossils found in Western Australia were remarkably similar to those found on the southern coast of England.

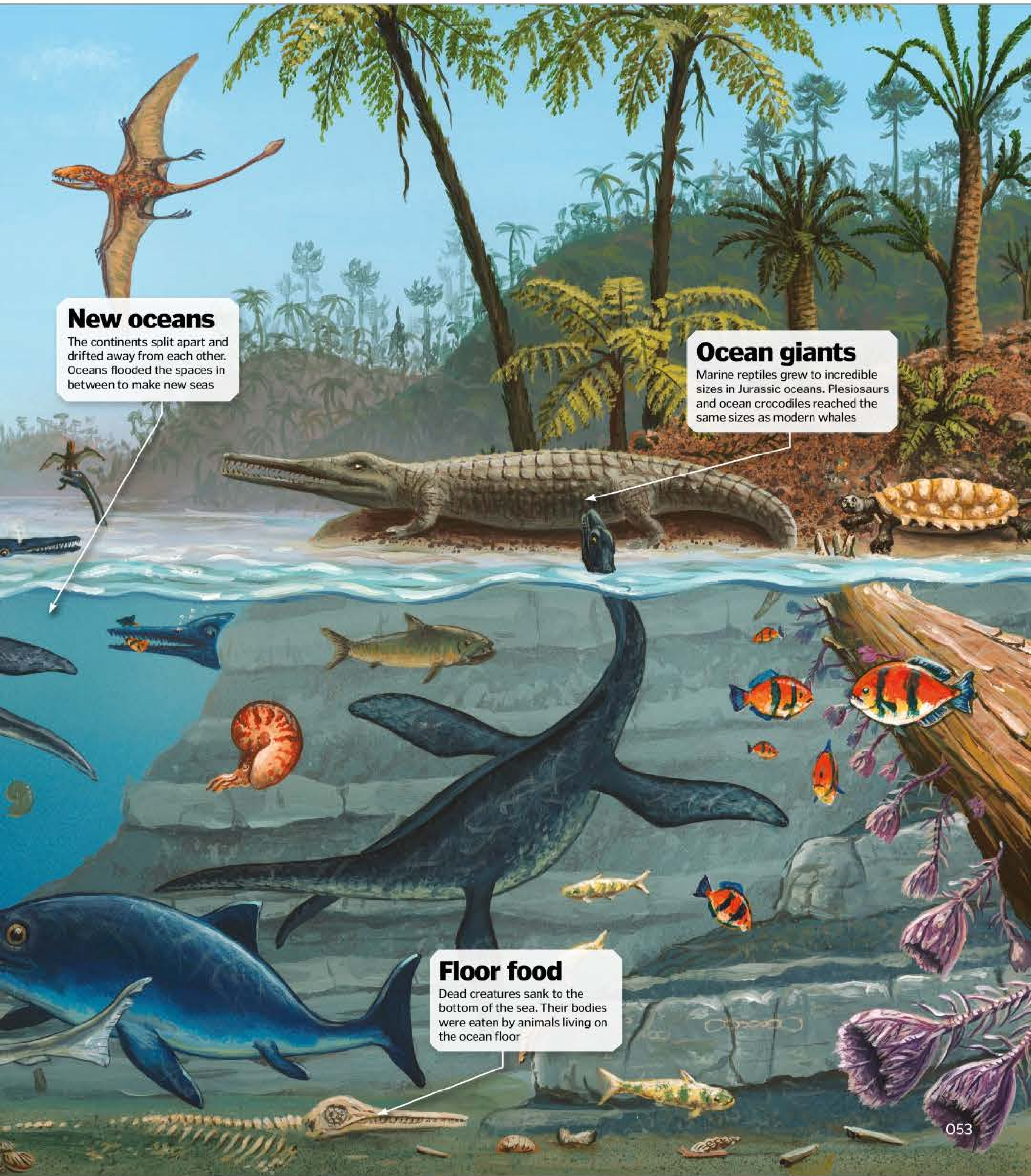
The oceans were a fiercely fought-over battleground, with large marine reptiles such as the Plesiosaurus dominating the shallower waters. With its stocky torso, four large flippers, an extremely long neck and a tiny skull filled with small teeth, the Plesiosaurus was an accomplished predator of fish, squid and other relatively small, fast-moving prey. Moving further out to sea, other sauropterygians, such as the Liopleurodon, ruled the waters. This reptile reached lengths of up to 10 metres and boasted a streamlined body that allowed it to soar through the water using its four paddle-like limbs. It could devour sizeable aquatic reptiles and large fish; in the survival of the fittest, this creature was a very prolific predator.



Oceanic predators
Plesiosaurs and Ichthyosaurs were top predators

Plenty of food

Smaller creatures like fish and molluscs were everywhere. They made easy meals for bigger beasts like reptiles, sharks and whales


New oceans
The continents split apart and drifted away from each other. Oceans flooded the spaces in between to make new seas
Ocean giants
Marine reptiles grew to incredible sizes in Jurassic oceans. Plesiosaurs and ocean crocodiles reached the same sizes as modern whales
Floor food
Dead creatures sank to the bottom of the sea. Their bodies were eaten by animals living on the ocean floor

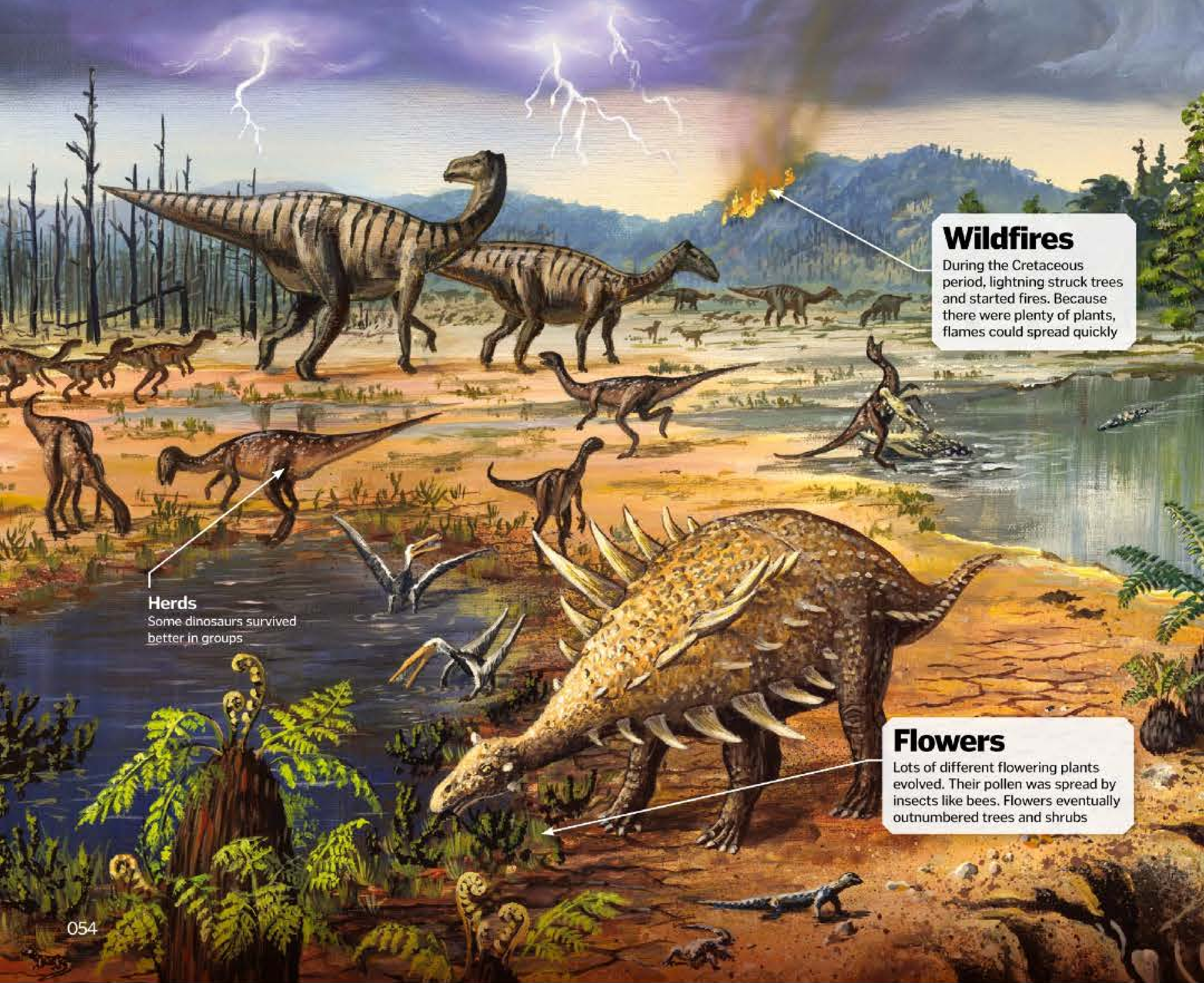
Cretaceous plains

145 to 66 million years ago

Life was not easy on the Cretaceous plains. Dinosaurs faced many changes to their habitat

The climate of the Cretaceous period consisted of global temperatures of around 10°C or 50°F higher than today and high atmospheric carbon dioxide levels. It was something of a greenhouse world. The high sea levels (approximately 200-300m higher than today) meant that swamp-like plains existed on the lower latitude areas where crocodylomorphs, such as the Simosuchus and Deinosuchus, began to thrive. The Deinosuchus, a member of the alligatoridae family that includes modern day alligators, weighed up to ten tons and was one of the most ferocious predators in North America. In fact, its habitat overlapped with tyrannosaurids, such as Daspletosaurus; in these ecosystems it was the powerful alligatorid, not the tyrannosaurids, that dominated.

Also during the Cretaceous period, the skies were inhabited by colossal pterosaurs, such as the Quetzalcoatlus. These beasts rank as the largest flying creatures of all time, with a wingspan larger than many small planes. However, thanks to a complex system of air sacs inside its bone structure, the Quetzalcoatlus weighed no more than 250kg. They were agile and fast in the air, making catching prey easy.



DID YOU KNOW? *The phenomenon of erupting volcanoes is known as volcanism*

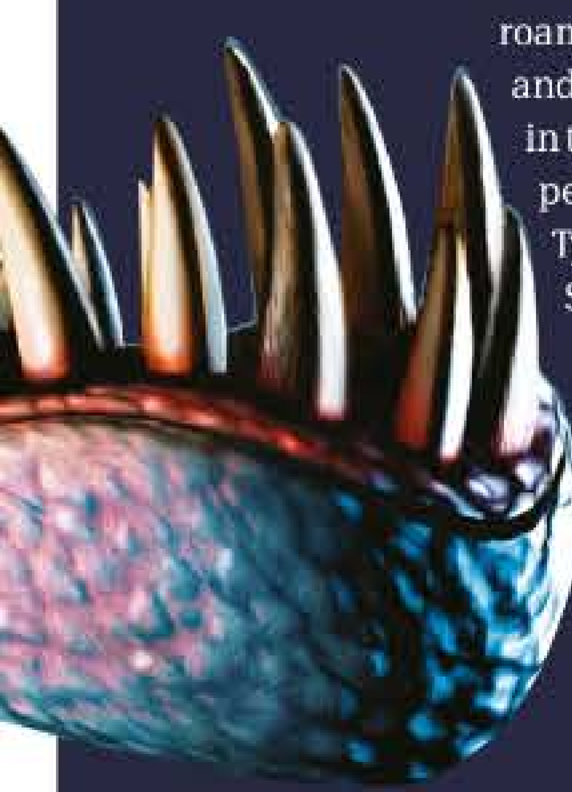
Prehistoric monsters

Meet the enormous ancient predators that stalked the land, dominated the oceans and terrorised the skies

Colossal Cretaceous carnivore

SPINOSAURUS ▶ 112-97 MYA

Move over T-rex: the spine lizard was the true king



Nearly three storeys high and longer than a bus, the Spinosaurus was the largest carnivorous dinosaur to walk the Earth. The 'spine lizard' roamed the coastal plains and swamps of North Africa in the mid-Cretaceous period. Unlike the Tyrannosaurus rex, Spinosaurus' teeth were not serrated, so they were not used for tearing through flesh; its conical teeth, powerful jaws and long snout were better suited to snapping up large fish. It's thought that Spinosaurus was the first dinosaur to swim, and that it spent a lot of time in the water where it could snatch unfortunate aquatic creatures with its razor-sharp claws. There is evidence to suggest Spinosaurus' snout openings and skull cavities were part of a pressure-detection system, so it could sense the movements of fish even in obscure and murky waters.

The giant carnivore's defining feature was the 1.5-metre-high 'sail' on its back, formed by tall vertebral spines. This may have been a display to attract mates or intimidate rivals, help regulate temperature, or possibly support a camel-like hump of stored fat that Spinosaurus could build up when food was plentiful.

Mega monitor lizard

VARANUS PRISCUS ▶ 1.8 MYA-40,000 YA

Also known as Megalania, these giant goannas of eastern Australia were the largest land lizards of all time. They could grow to lengths of over five metres and weigh as much as 600 kilograms. Megalania had razor-sharp teeth and claws, perfect for tearing into its prey. These large lizards compensated for their lack of speed by lying in wait to ambush victims, and sought out carrion using their excellent sense of smell.

Super-sized serpent

TITANOBOA ▶ 60-58 MYA

Reaching lengths of up to 15 metres, Titanoboa was one of the largest land animals on Earth following the extinction of the dinosaurs. These colossal serpents lived in the jungles of South America, devouring turtles and crocodiles in single mouthfuls. Titanoboa could hunt on land and in water, slithering or swimming up to its prey undetected, then suddenly leaping up to clamp its powerful jaws over the victim's windpipe.

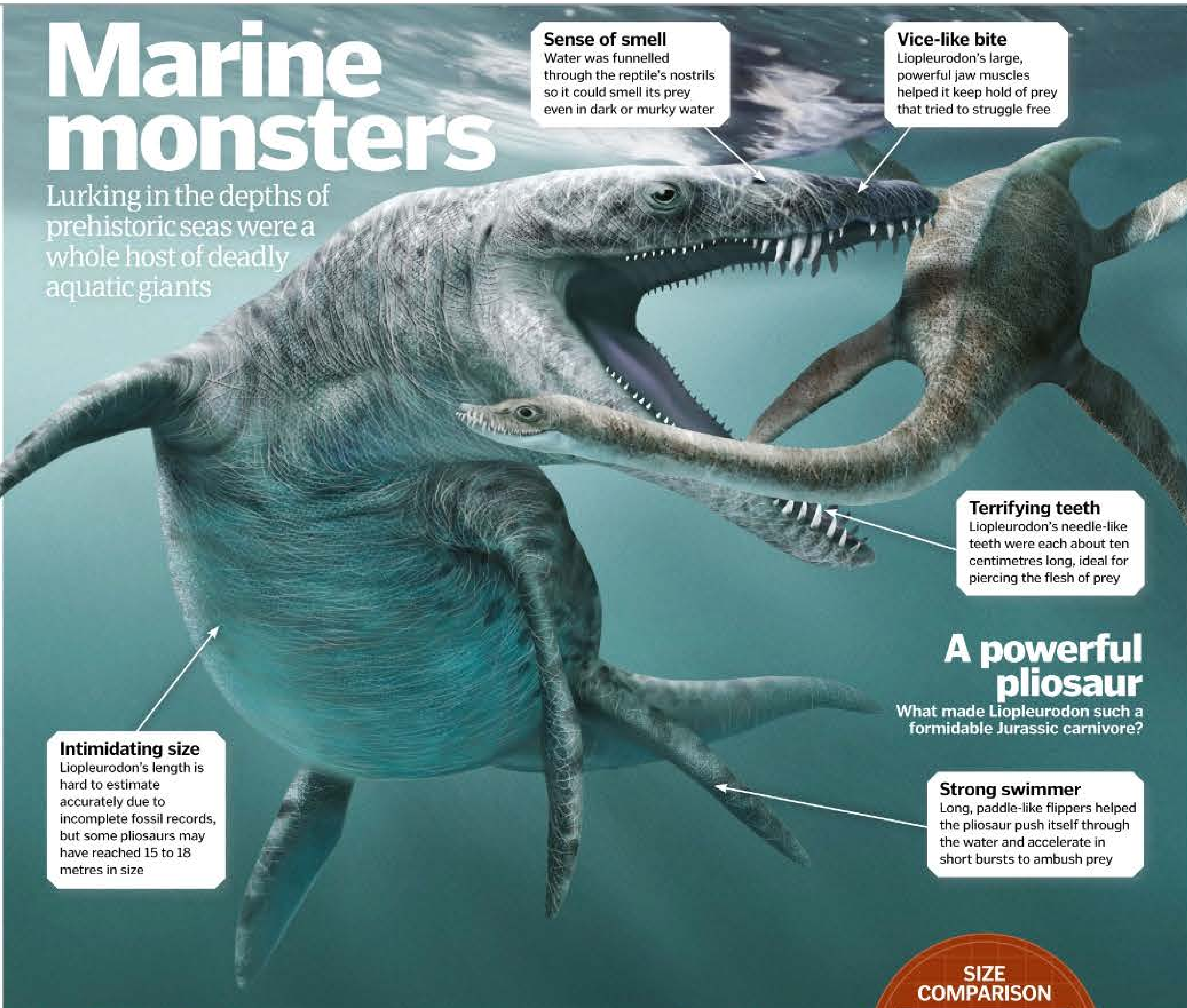
Terror birds

PHORUSRHACIDAE ▶ 62-2 MYA

These terrifying predators of prehistoric South America were members of the Phorusrhacidae family, known as 'terror birds', and some could reach heights of three metres. Their main weapon was a sharp, hooked beak that could strike victims from above like a pickaxe. The birds' legs were also incredibly strong, and they may have used their feet to kill by repeatedly kicking, or thrown their prey violently to tenderise the meat.

Marine monsters

Lurking in the depths of prehistoric seas were a whole host of deadly aquatic giants



A powerful pliosaur

What made Liopleurodon such a formidable Jurassic carnivore?

Mighty ocean predator

LIOPLEURODON ► 160-155 MYA

A fierce killer with a bone-crunching bite

Liopleurodon was among the most powerful predators ever known on Earth, with a bite possibly even stronger than that of the mighty T-rex. It belonged to a group of marine reptiles called pliosaurs, which were large with short necks. Liopleurodon's diet primarily consisted of fish and squid, but it would occasionally seek out much larger prey. Huge bite marks that were found in plesiosaur fossils suggest that they were victims of the Liopleurodon's massive jaws, which were packed with sharp teeth. Scientists even estimate that these colossal carnivores would have been strong enough to bite a car in half, if they had existed at the same time!

Liopleurodon may have also had a pale underside to help keep it camouflaged from prey below, allowing it to make ambush attacks despite its enormous size.

Giant sea scorpion

PENTECOPTERUS ▶ 467 MYA

Over 200 million years before the first dinosaurs emerged, this nightmarish Pentecopterus was an important Palaeozoic predator. These arthropods grew to lengths of around 1.8 metres, and used their large limbs to grab prey. Young lived on the seabed while adults mainly resided in shallow waters to avoid larger predators. These super-sized scorpions also had hairs that helped them to sense the movement of their prey.

King-sized croc

MACHIMOSAURUS ▶ 130 MYA

Lurking in Cretaceous seas, Machimosaurus was a colossal crocodile at nearly ten metres long, almost twice the size of its biggest modern relatives. Its teeth were best suited for crushing shells and crunching bones rather than slicing through flesh. Machimosaurus' main tactic was to hide in shallow water and, without warning, clamp its mouth shut on a turtle or fish. Once its prey was caught in the jaws, there would be no escape.

Apex ocean reptile

MOSASAURUS ▶ 80-66 MYA

The massive Mosasaurus was a giant aquatic lizard and dominant predator in Cretaceous-era oceans. Some grew to 15 metres or more, and had long, powerful tails to propel themselves through water. They preyed on reptiles, fish, sharks and shellfish, snapping their tough shells with its powerful jaws. As an air-breather, Mosasaurus was unable to dive for prolonged periods, so it was limited to hunting near the ocean surface.

A real-life leviathan

LIVYATAN ▶ 13-12 MYA

A killer sperm whale with one of history's biggest bites

Hebrew for 'leviathan', Livyatan was roughly the same size as a modern sperm whale, but it was a much more formidable hunter. The 50-ton beasts probably competed with Megalodon for food, preying on smaller whales, cetaceans like dolphins, and large fish. Livyatan teeth are possibly the largest of any animal at over 30 centimetres long, and its bite force could rival that of the Megalodon.

Super-sized shark

MEGALODON ▶ 28-1.6 MYA

Meet the colossal sharks that dwarfed great whites

These gigantic 75-ton sharks were so big that they could hunt whales with ease. Up to 20 metres long and equipped with a mouth full of teeth as large as a human hand, these mega-sharks made short work of dolphins, whales, seals, squid and other sharks. When faced with a turtle shell, they snapped it in two. It is estimated that Megalodon had one of the strongest bite forces of any animal that's ever lived, capable of crushing a small car.

Sky giants

The huge aerial predators that brought death from above

Haast's eagles were eventually driven to extinction as they competed with humans for moas, their preferred prey

Jumbo raptor

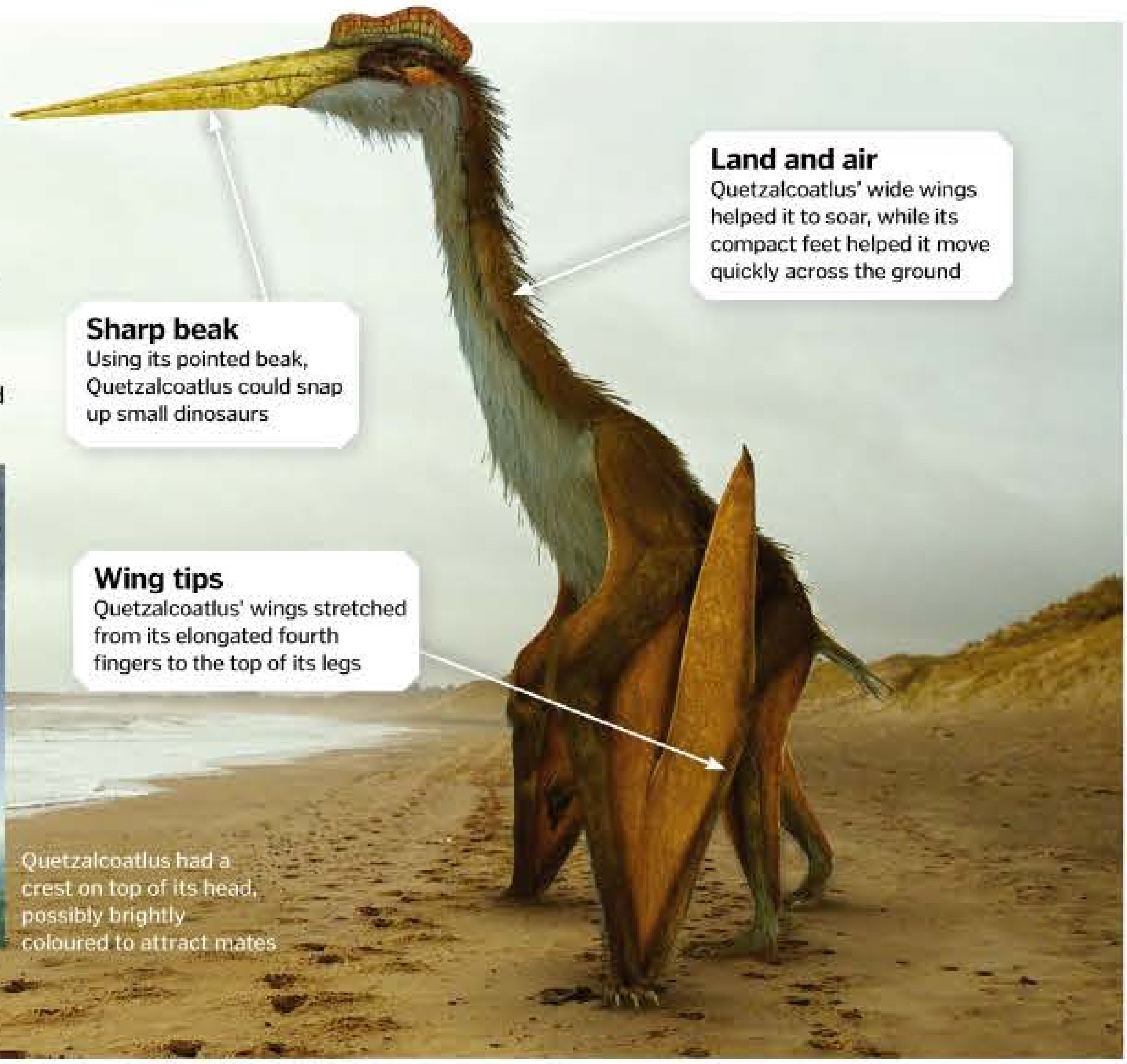
HAAST'S EAGLE ► 1.8 MYA-1400 CE

With talons the size of tigers' claws, these monstrous eagles preyed on helpless herbivores of New Zealand's South Island. Swooping at speeds of up to 80 kilometres per hour, they could knock victims off their feet with the sheer force of impact. Their favourite prey were giant flightless birds called moas, which could weigh up to 250 kilograms. Compared to the size of its body, Haast's eagles' three-metre wingspan was relatively short. This meant that they would have killed moas on the ground rather than carry them away. Their terrifying, razor-sharp talons could quickly incapacitate victims by delivering crushing blows to their head or neck.

Plane-sized pterosaur

QUETZALCOATLUS NORTHROPI ► 70-65 MYA

Quetzalcoatlus was the largest-known species of pterosaur, the group of flying reptiles that lived alongside dinosaurs. With a wingspan of ten metres or more, it was roughly the size of a small jet plane. Its toothless beak suggests that it hunted small prey that didn't require chewing, such as baby dinosaurs, and possibly also scavenged for carrion. Quetzalcoatlus is also thought to have roamed on land, because it had small, cushioned feet that were suited to moving over firm terrain. If this is true, it may have hunted like a modern-day stork, snatching small prey up in its beak.



Quetzalcoatlus had a crest on top of its head, possibly brightly coloured to attract mates

DID YOU KNOW? One of the largest dinosaurs discovered so far is an as-yet-unnamed, 37m-long, 70-ton Titanosaur

ARGENTAVIS ▶ 6 MYA

Dwarfing even the Haast's eagle, Argentavis is one of the largest birds to have ever lived. Its seven-metre wingspan meant it was suited to gliding rather than flapping, and it used air currents to stay aloft. Argentavis' massive size made it impossible to perform a running take-off, so it relied on height to get airborne, taking advantage of slopes and headwinds like a hang-glider pilot. The so-called 'monster bird' could use its sharp talons and hooked beak to attack its prey, soaring over vast areas of land in search of victims. Argentavis may have also scavenged, its intimidating size driving other hunters away from a kill, in order to help itself to the carcass.

Gliding bird
Argentavis' long wings enabled it to glide on wind currents and updrafts

Achieving flight
To get airborne the bird would run down slopes and leap into the air

Scavenger
Argentavis' imposing size meant it could scare away other predators from their own kills

Gigantic fly

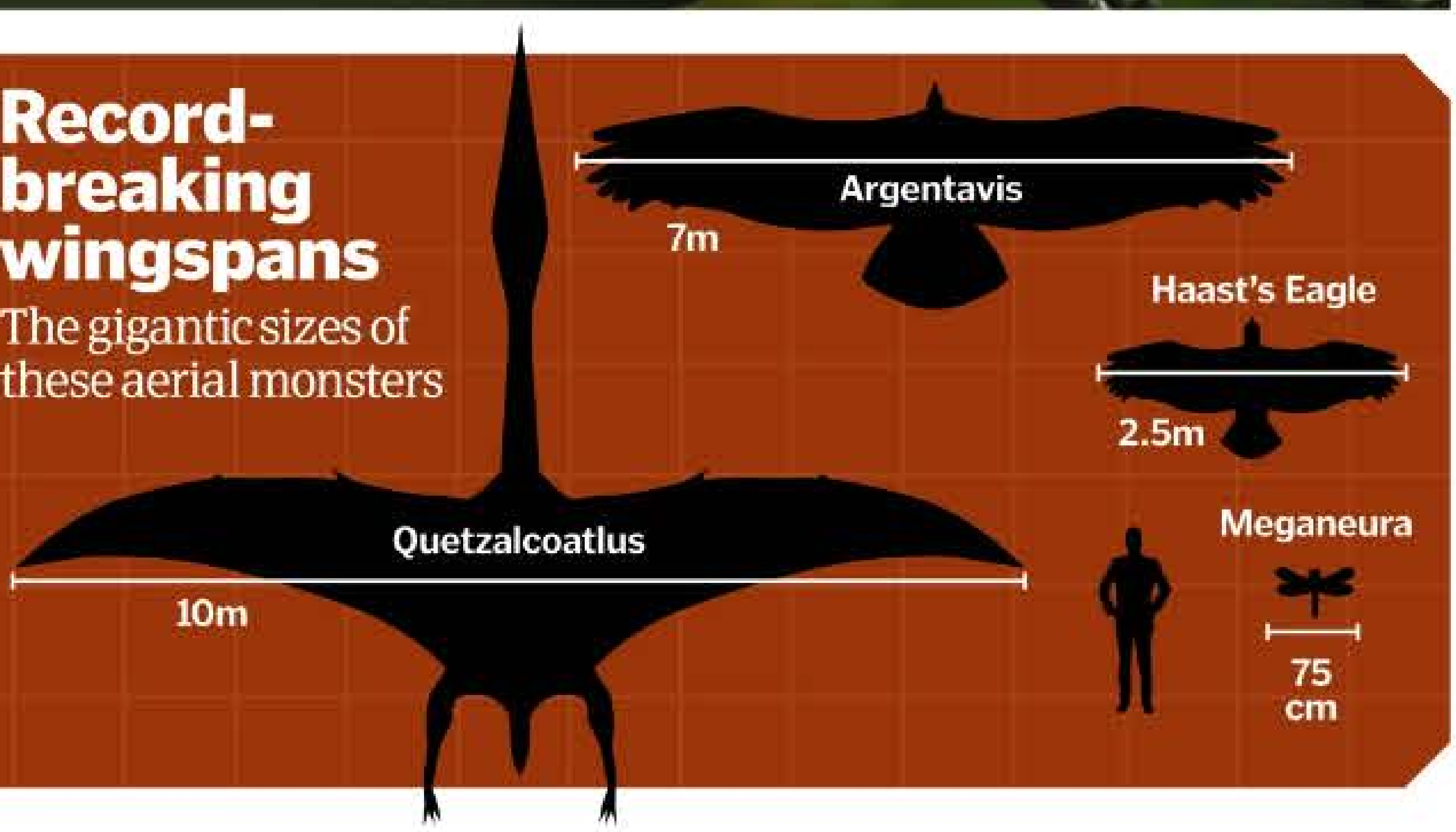
MEGANEURA ▶ 300 MYA

One of the biggest insects to ever exist, the Meganeura was a member of the griffinflies, which are closely related to dragonflies. This prehistoric insect benefited from a higher percentage of oxygen in the atmosphere in the period in which it lived. This allowed it to grow to and maintain its huge size. It used its large eyes to spot prey such as small amphibians and other insects, which it grabbed with its legs while in midair.

The Meganeura's 75-centimetre wingspan was larger than that of a magpie

Record-breaking wingspans

The gigantic sizes of these aerial monsters



Why were prehistoric animals so big?

It had previously been accepted that prehistoric animal size was a result of Cope's Rule. Named after American palaeontologist Edward Drinker Cope, the theory suggested that dinosaur gigantism was down to the notion that animals naturally evolve to be bigger. When mass extinctions occur, new smaller animals replace the larger extinct ones, and the process begins anew. As it has 'only' been 66 million years since the Cretaceous mass extinction, and 12,000 years since the last ice age, animals on Earth are now smaller because they haven't yet had enough time to evolve to reach such large sizes once again.

Another theory suggested that environmental factors, such as higher oxygen levels and warmer temperatures, could have played a significant role in gigantism. Cold-blooded reptiles benefited from the toasty climate as it allowed for efficient digestion, circulation and respiration, as well as an abundance of vegetation to consume.

More recent research and fossil discoveries have cast doubt on both these theories, though. Some creatures seemed to evolve to be smaller rather than larger over time, and many different-sized animals existed at the time. One explanation for why dinosaurs in particular were typically large is because they where physiologically similar to birds. Their bones had air pockets in them, making even large species relatively light, so they wouldn't collapse under the weight of their own bodies.

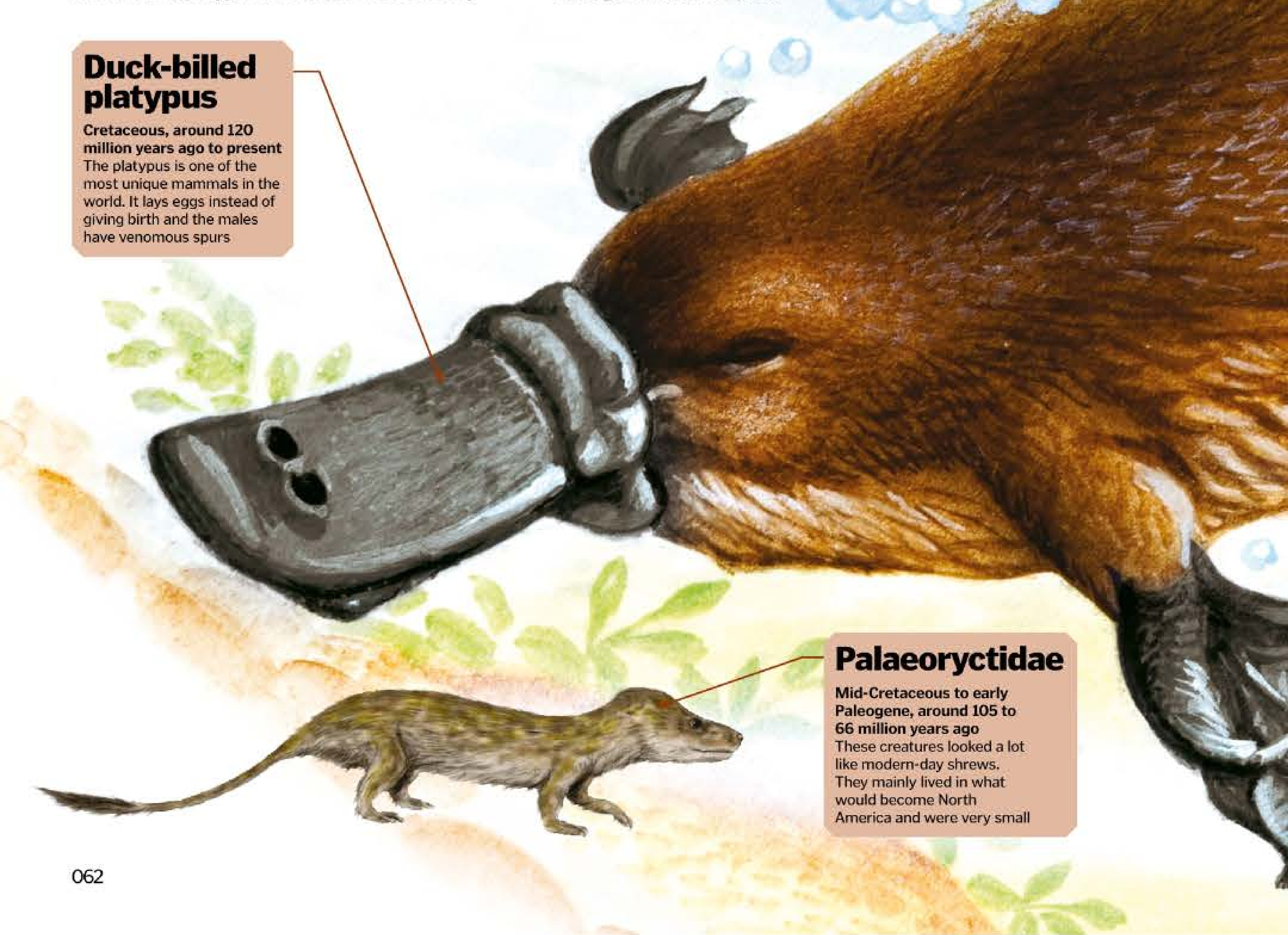
Not all of the biggest beasts were prehistoric, though. In fact, the heaviest animal ever to exist on planet Earth is still alive today: the blue whale. Marine animals can grow to epic proportions because the buoyancy from water helps to balance the force due to gravity. This supports their considerable masses, and allows for far larger body sizes than on land.

The dinosaurs' neighbours

Tiny mammals lived alongside dinosaurs in the Mesozoic era. While many are now extinct, some of their descendants are still alive today

Mammals are characterised in many different ways, such as the possession of hair and mammary glands that produce milk for their offspring. While it is the formidable dinosaurs that people associate most with the Mesozoic era, mammals also lived and evolved during this era. For example, during the early Cretaceous period, egg-laying mammals, such as the Teinolophos, existed. Little is actually known about this mammal as only a few partial lower-jaw bones have ever been discovered. Certain characteristics of these jaw bones indicated that the Teinolophos was indeed a monotreme – an egg-laying mammal. The platypus and the echidna are the only remaining monotremes. They are found only in Australia, where the Teinolophos lived around 120 million years ago.

Going further back into the late Jurassic period, there existed the Multituberculata – a small rodent-like mammal that occupied the northern hemisphere. Examples of these mammals include Ptilodus, which largely resemble modern-day squirrels thanks to their sharp claws that grip onto the bark of trees and feet that can be reversed backwards to allow the animals to climb down trees with their heads pointing downwards. Here are just a few example of the mammals that existed throughout the Mesozoic era.



Multituberculata

Late-Jurassic to early-Oligocene, 160 to 35 million years ago
This group of little mammals was around for roughly 120 million years. It's the longest-surviving mammal group on record

"Mammals were able to successfully occupy empty niches once the dinosaurs died out"

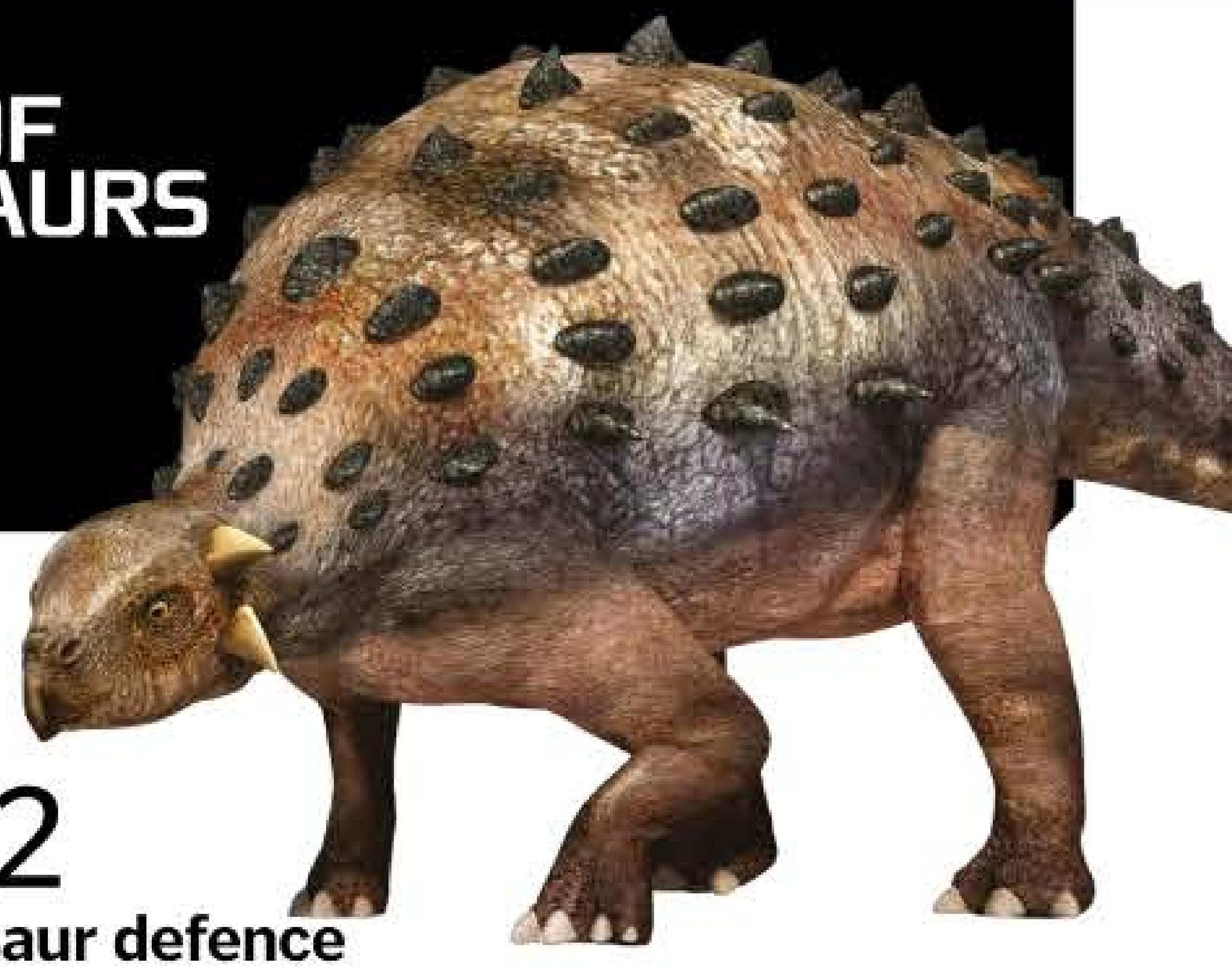
Cynognathus

Triassic, around 230 million years ago
These creatures were also technically mammal-like lizards. They had many features in common with mammals, such as hair and possibly even warm blood

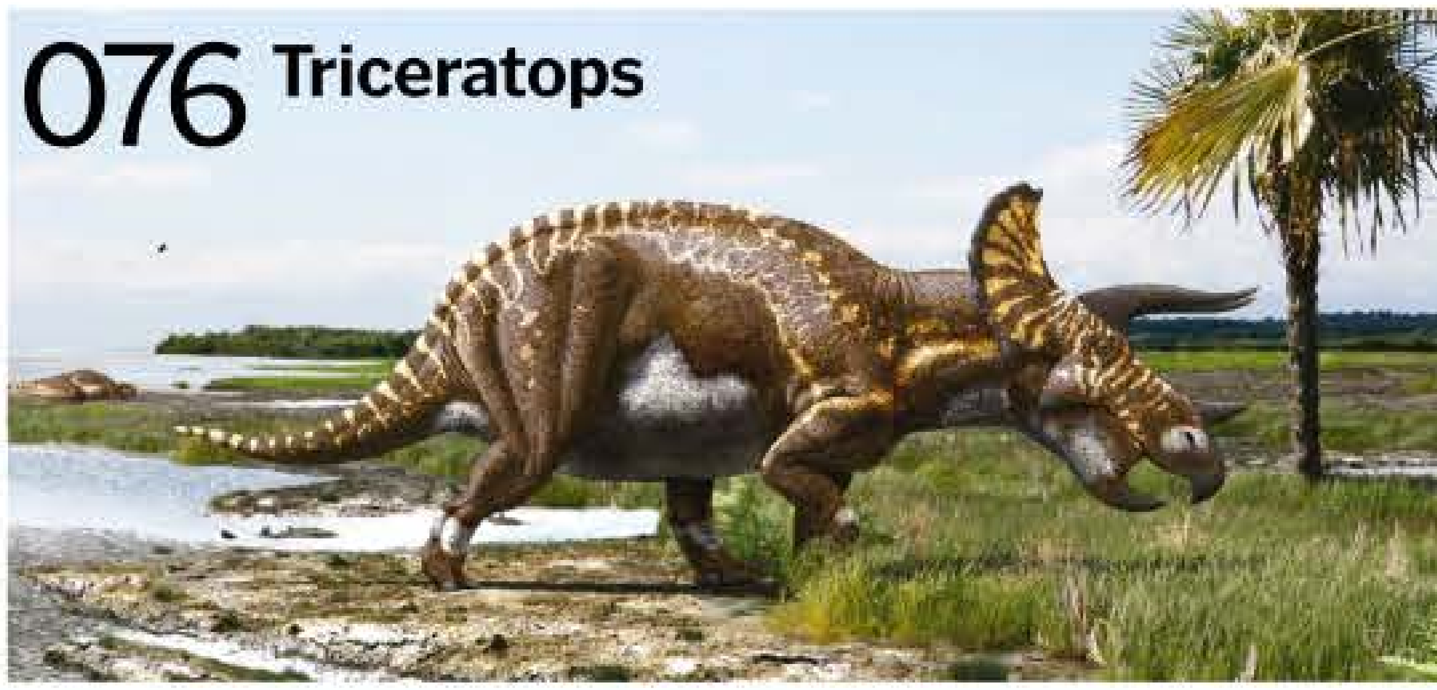
HOW IT WORKS BOOK OF DINOSAURS

DINOSAURS

Dinosaurs

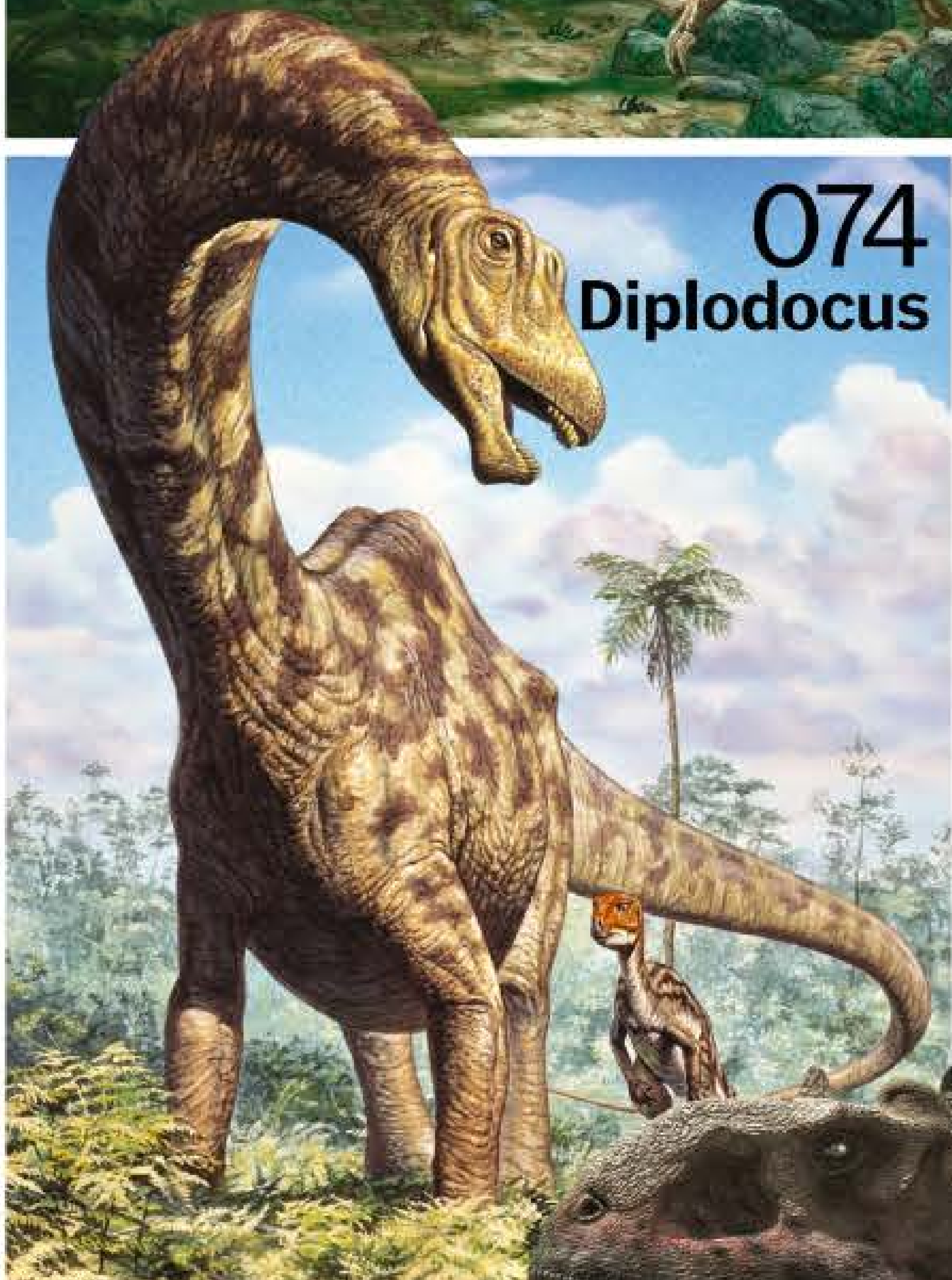


072 **Dinosaur defence**



078
Velociraptor

066
Inside a dinosaur egg



074
Diplodocus

094
Troodon

068
Class of the titans

082
T-rex

What was inside a dinosaur egg?

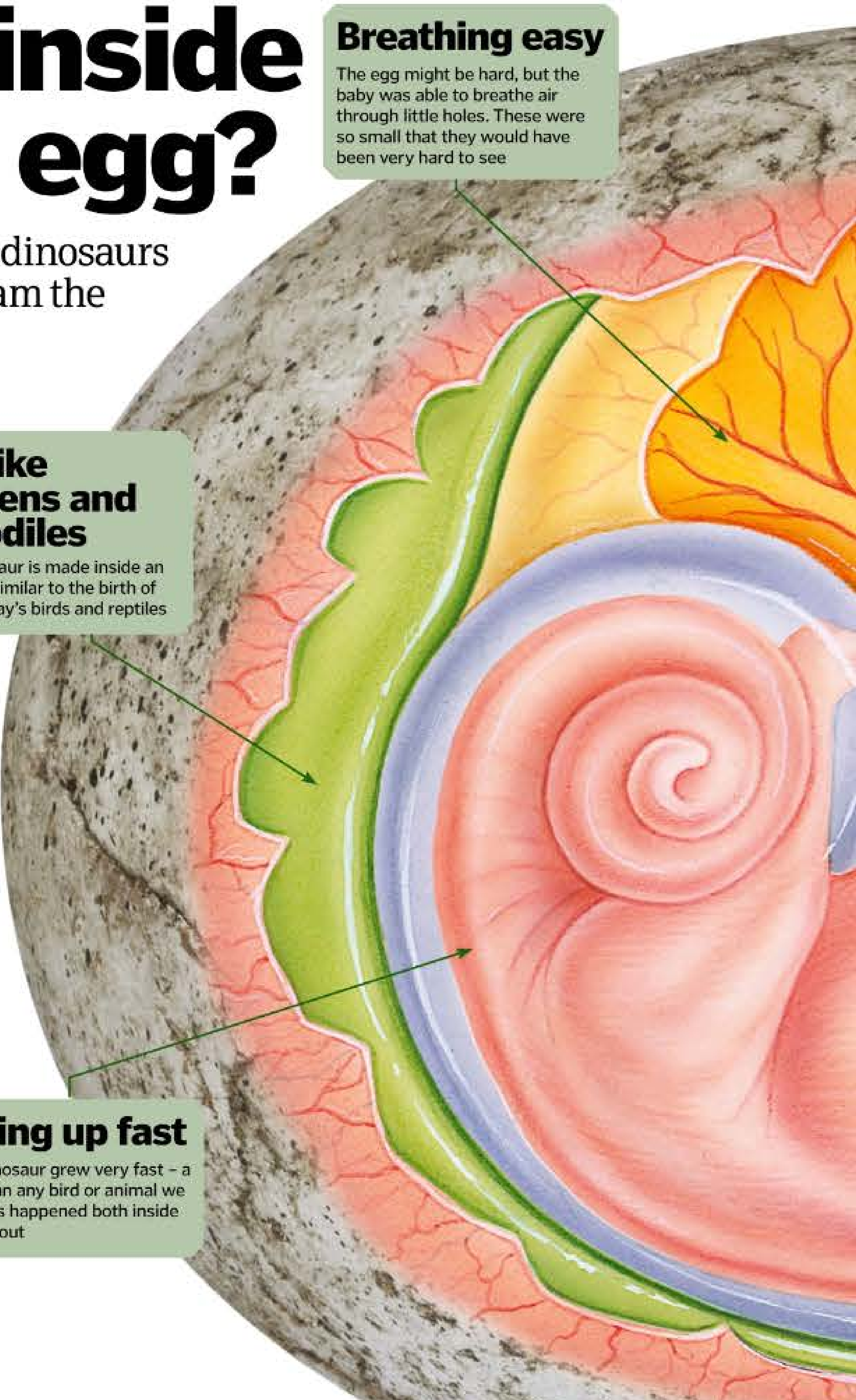
Just like modern day baby chicks, dinosaurs grew and hatched from eggs to roam the planet a very long time ago

What came first – the dinosaur or the egg? We're not entirely sure, but what we do know is that these great reptiles laid eggs just like chickens do. Inside the shell of a hen's egg, chicks are able to grow before they're ready to hatch. That's just how the dinosaurs were born.

We know that baby dinosaurs were made this way because we have found lots of evidence. Fossilised dinosaur eggs have been found at over 200 sites across the world. They tell a story about how the dinosaur made its nest, laid its eggs and how baby dinosaurs were born.

A crew of palaeontologists exploring Mongolia in 1923 were the first to scientifically recognise fossilised dinosaur eggs for what they were. Since then many dinosaur nesting sites for many different species have been uncovered all around the world. The oldest known dinosaur eggs and embryos date back to the Early Jurassic (about 190 million years ago) and come from the Massospondylus, a bipedal, omnivorous prosauropod.

Egg Mountain in Montana, USA is the site of one of the most famous dinosaur nest discoveries. Maiasaura remains were found near a nest with the remains of eggshells and babies too large to be hatchlings and this is the reason why Maiasaura is known as "caring mother lizard". Maiasaura and many other species of dinosaur, raised their young in nest colonies. This reflected the way that they herded when on the move. This amazing discovery was the first proof that dinosaurs raised and fed their young, rather than leaving hatchlings to fend for themselves like modern turtles do. Nests contained approximately 30-40 eggs and were not incubated by the parent sitting on them, but by the heat produced from rotting vegetation placed in the nest. It's thought that Maiasaura hatchlings left the nest after a year or two of rapid growth.



Breathing easy

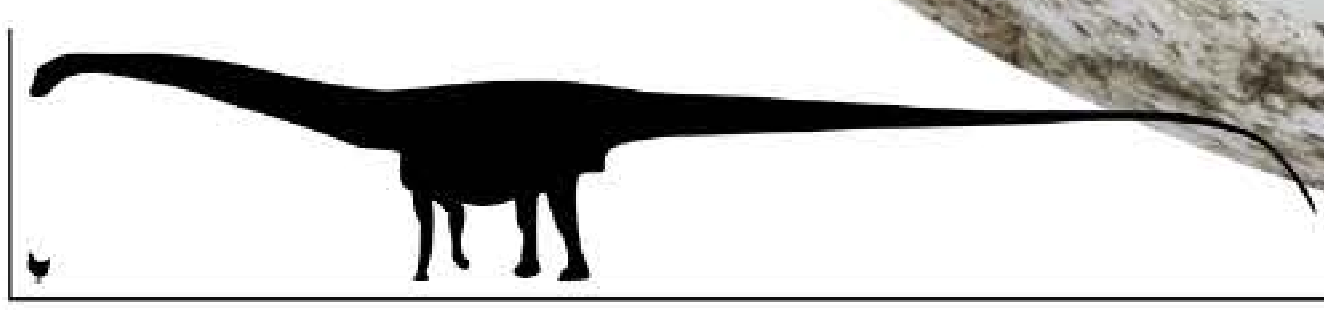
The egg might be hard, but the baby was able to breathe air through little holes. These were so small that they would have been very hard to see

Just like chickens and crocodiles

How a dinosaur is made inside an egg is very similar to the birth of many of today's birds and reptiles

Growing up fast

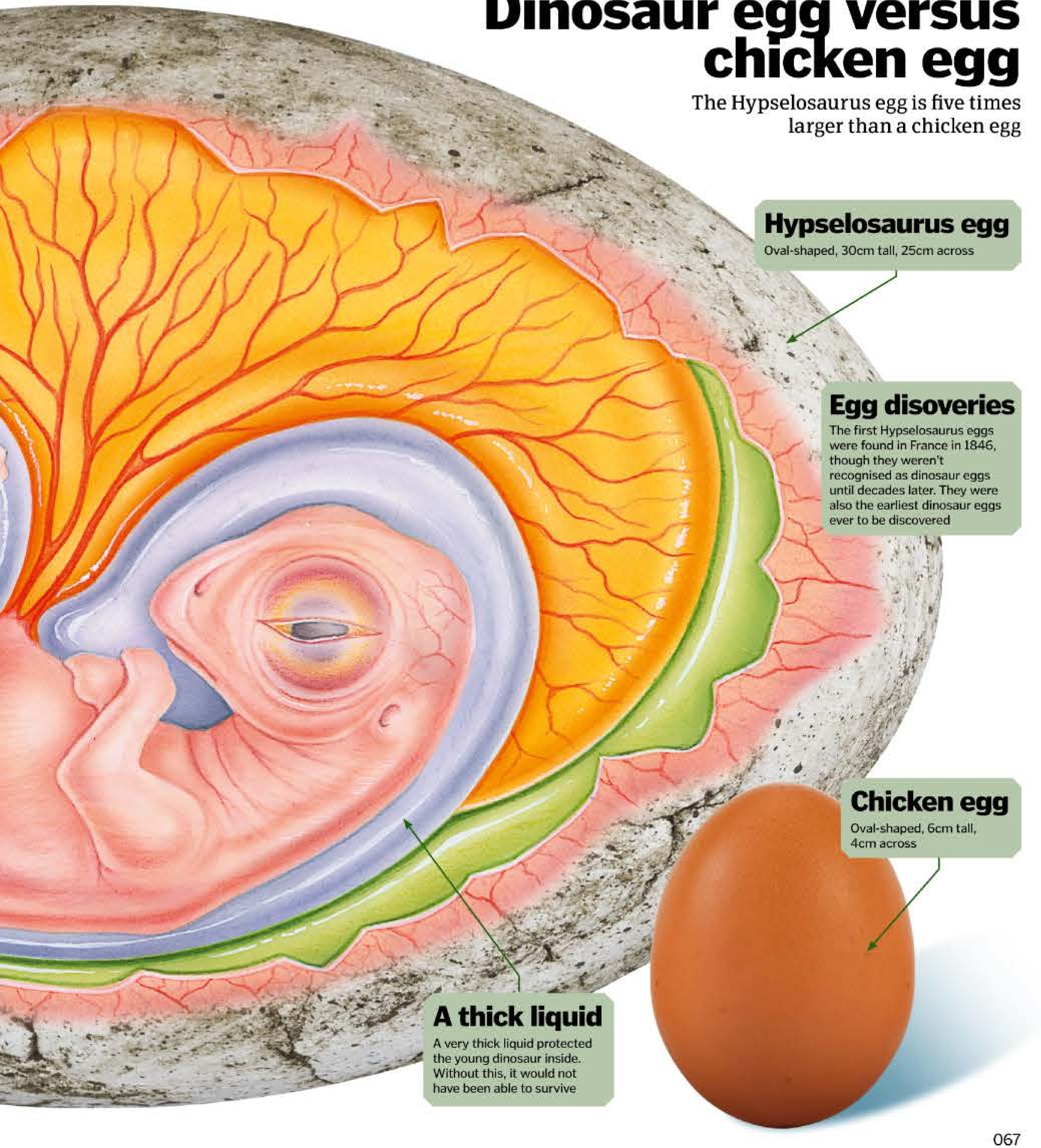
The baby dinosaur grew very fast – a lot faster than any bird or animal we know of. This happened both inside the egg and out



DID YOU KNOW? *Some dinosaurs were able to lay more than 30 eggs at a time*

Dinosaur egg versus chicken egg

The Hypselosaurus egg is five times larger than a chicken egg



Class of the Titans

Meet some of the largest dinosaurs to have ever roamed prehistoric Earth

In an era where humans dominate the land, it is rare for us to encounter animals bigger than ourselves in our daily lives. However, if we had existed during the Cretaceous period, Sauropods would have had us running for the hills. One particular giant has been hitting the headlines this year after finally getting a name. Discovered in 2012, the *Patagotitan mayorum* was a plant-eating, long-necked, stomping giant that weighed more than 11 African elephants: it is among the largest animals to have ever walked the Earth.

The unearthing of this giant began at the La Flecha farm in Patagonia, Argentina, when a ranch worker named Aurelio Hernández came across one of over 200 fossils of this gigantic Titanosaur. The specimens collected from the site are believed to have come from at least six individual patagotitans to form the most complete anatomical reconstruction of a Sauropod to date.

DISCOVERING A GIANT

As the heavyweight champion of the Titanosaurs, the patagotitan weighed in at around 69 tons, making the largest nine-ton *Tyrannosaurus rex* look minuscule. Stretching out from head to tail, this titan measures around 37 metres, the same length as around eight London taxis lined up next to each other.

Determining the weight of the patagotitan is difficult, with multiple methods being used among palaeontologists. Lead palaeontologist Dr Diego Pol and his team used two methods to calculate the patagotitan's body mass. The first method used an equation requiring the circumferences of the main limbs that supported its body, the femur and humerus, to estimate the weight they could support. An alternative method was to 3D scan each of the fossils to form a complete reconstruction of the patagotitan and estimate the volume of the surrounding soft tissue. Researchers believe that these fossilised remains are possibly from a

"Stretching out from head to tail, this titan measures around 37 metres"

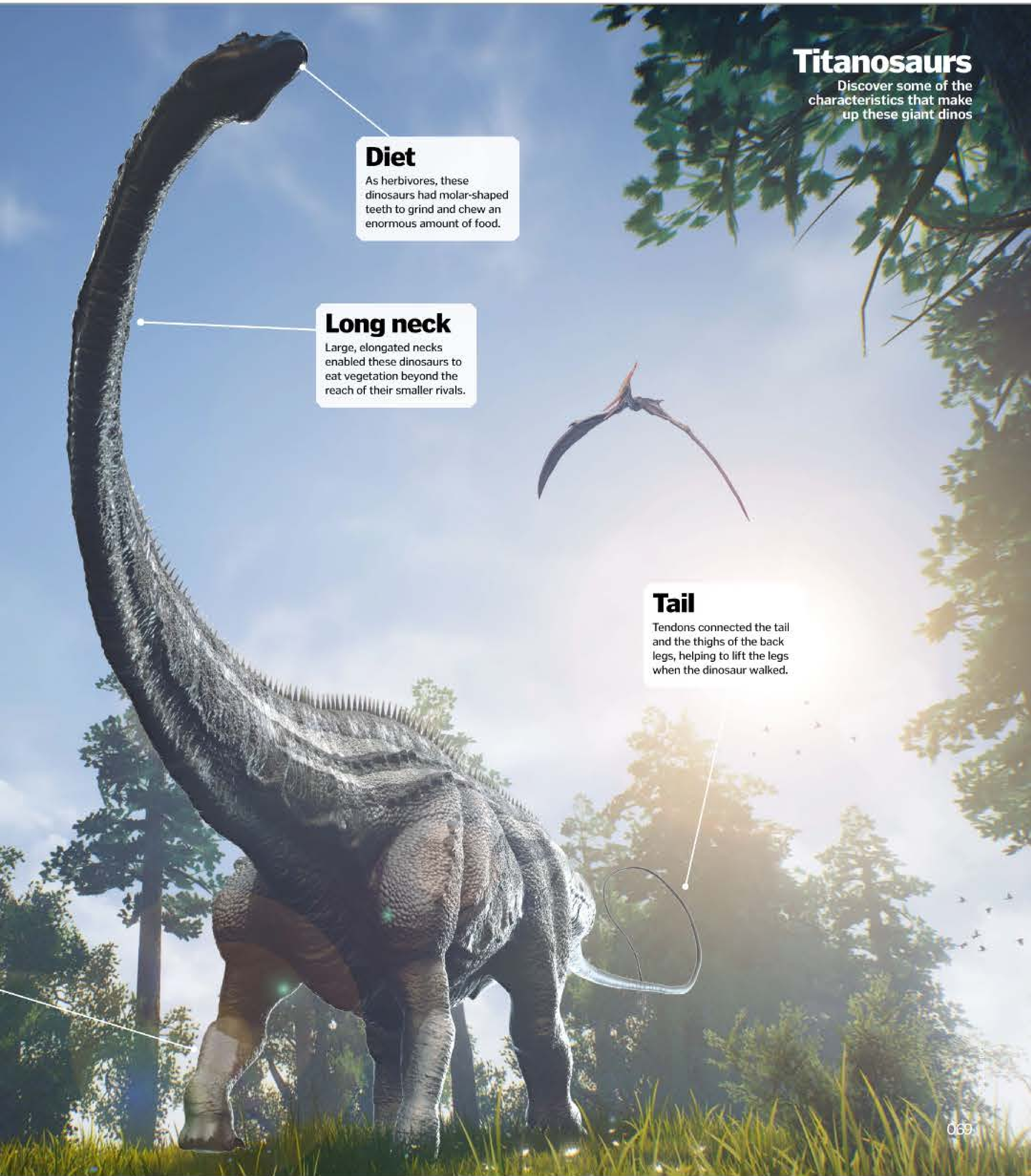
Movement

These massive, slow-moving giants put most of their energy into eating to stay alive, but it was also more difficult to move with their larger limbs.

DID YOU KNOW? *The word 'Sauropod' derives from Greek, meaning 'lizard-foot'*

Titanosaurs

Discover some of the characteristics that make up these giant dinos



Diet

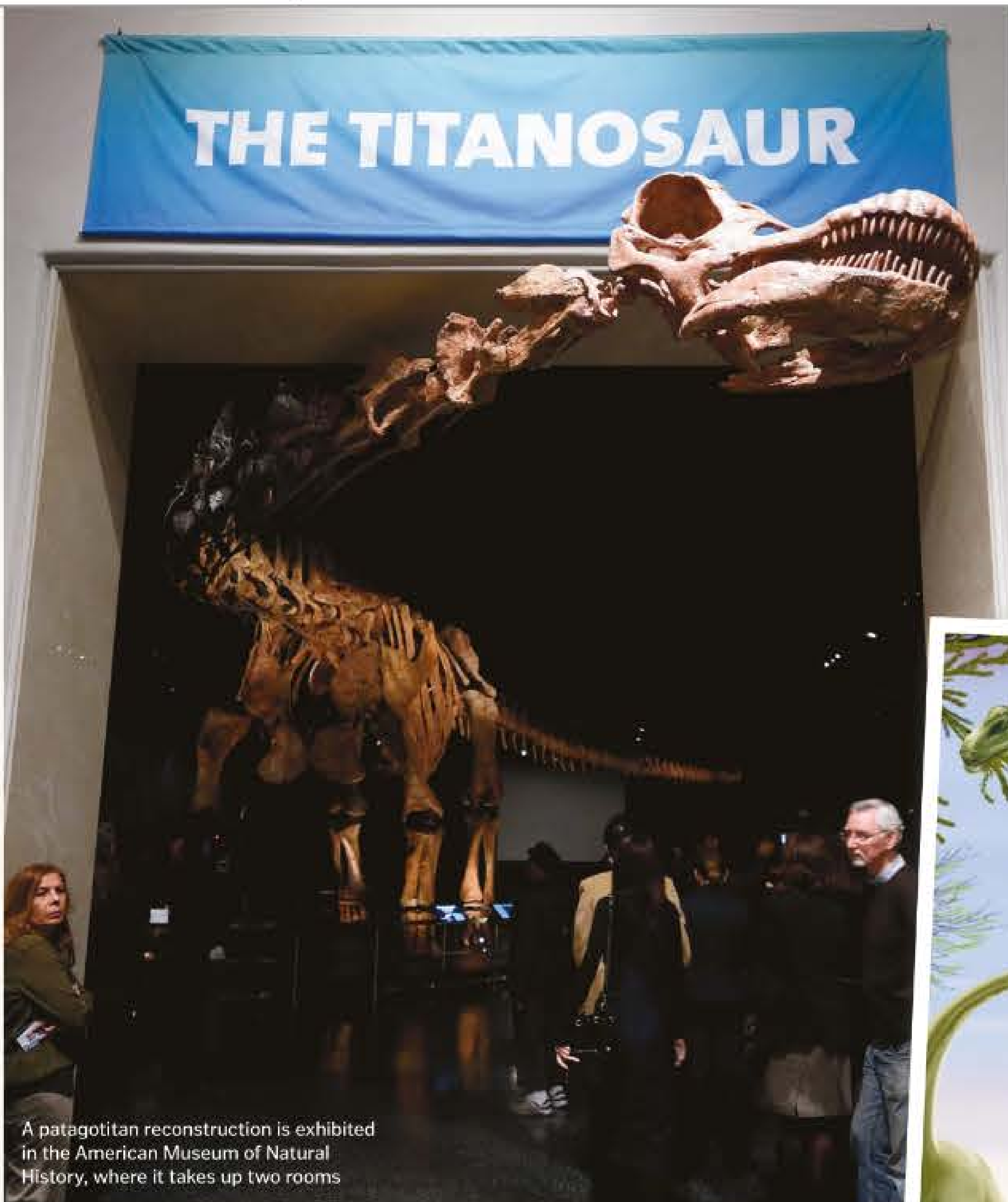
As herbivores, these dinosaurs had molar-shaped teeth to grind and chew an enormous amount of food.

Long neck

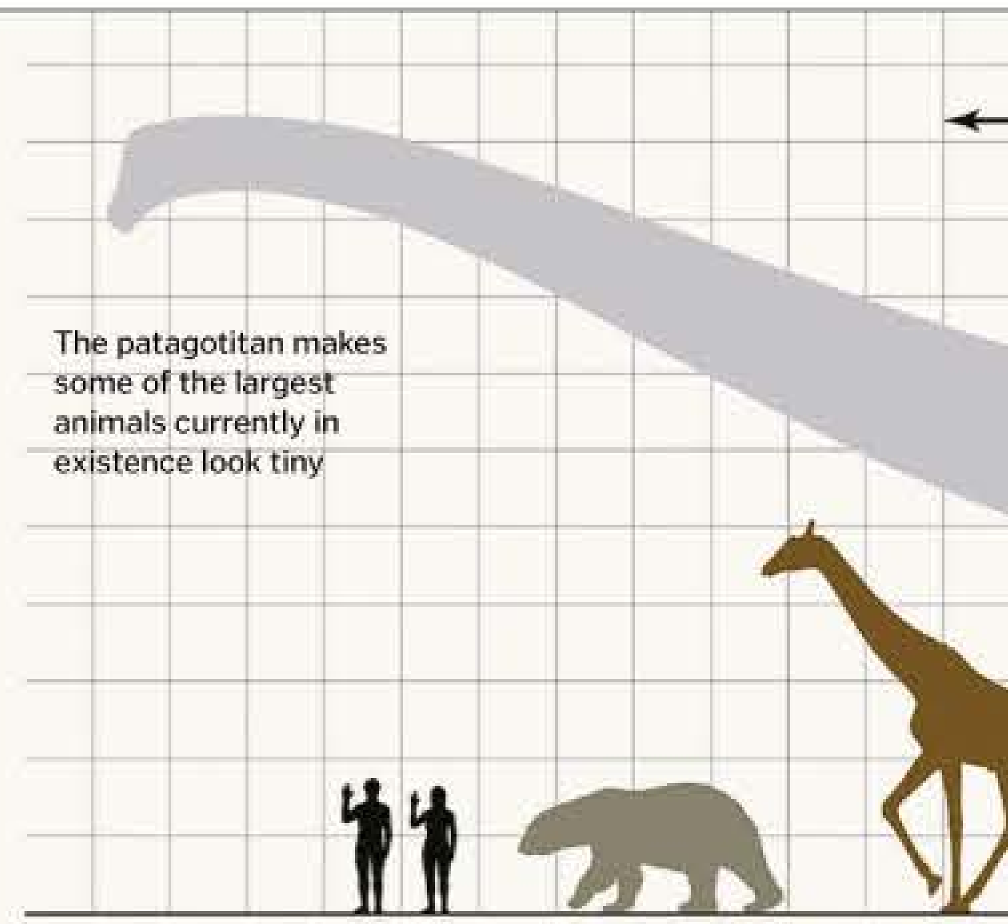
Large, elongated necks enabled these dinosaurs to eat vegetation beyond the reach of their smaller rivals.

Tail

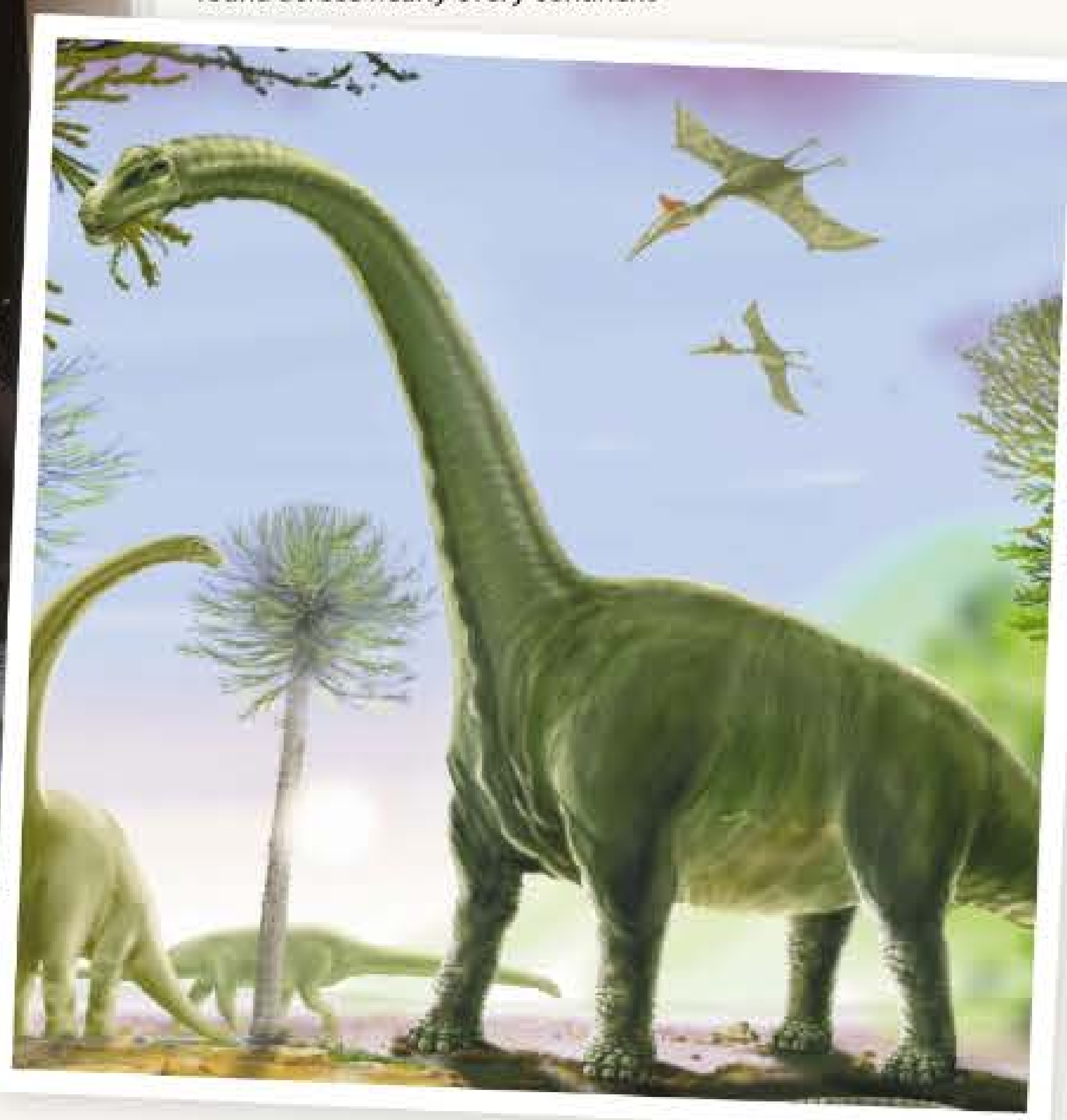
Tendons connected the tail and the thighs of the back legs, helping to lift the legs when the dinosaur walked.



A patagotitan reconstruction is exhibited in the American Museum of Natural History, where it takes up two rooms


The patagotitan makes some of the largest animals currently in existence look tiny

Evidence of Titanosaur fossils have been found across nearly every continent



specimen that is not fully grown, so maybe there are bigger dinosaurs to unearth.

However, it's not just the size and mass of a patagotitan that the fossil specimen can show us: it also reveals some of its behaviours and movements. Examining the teeth of dinosaurs can indicate their diet; a mouth full of grinding molars indicates a vegetarian diet, like the patagotitan and other Sauropods.

In the case of the patagotitan, the archaeological team found three levels of specimens in the same location on a floodplain, where the dinosaur's remains were covered over time by sediment brought over by the flooding water. This occurred at least three times at this site, indicating that the prehistoric giants had visited this site on at least three separate occasions. Much like we see in elephants, some of the fossil specimens of the patagotitan even had marks suggesting living patagotitans had stepped on them. It has been speculated that due to periods of drought, these beasts may have died from dehydration by becoming entrapped in the surrounding mud.

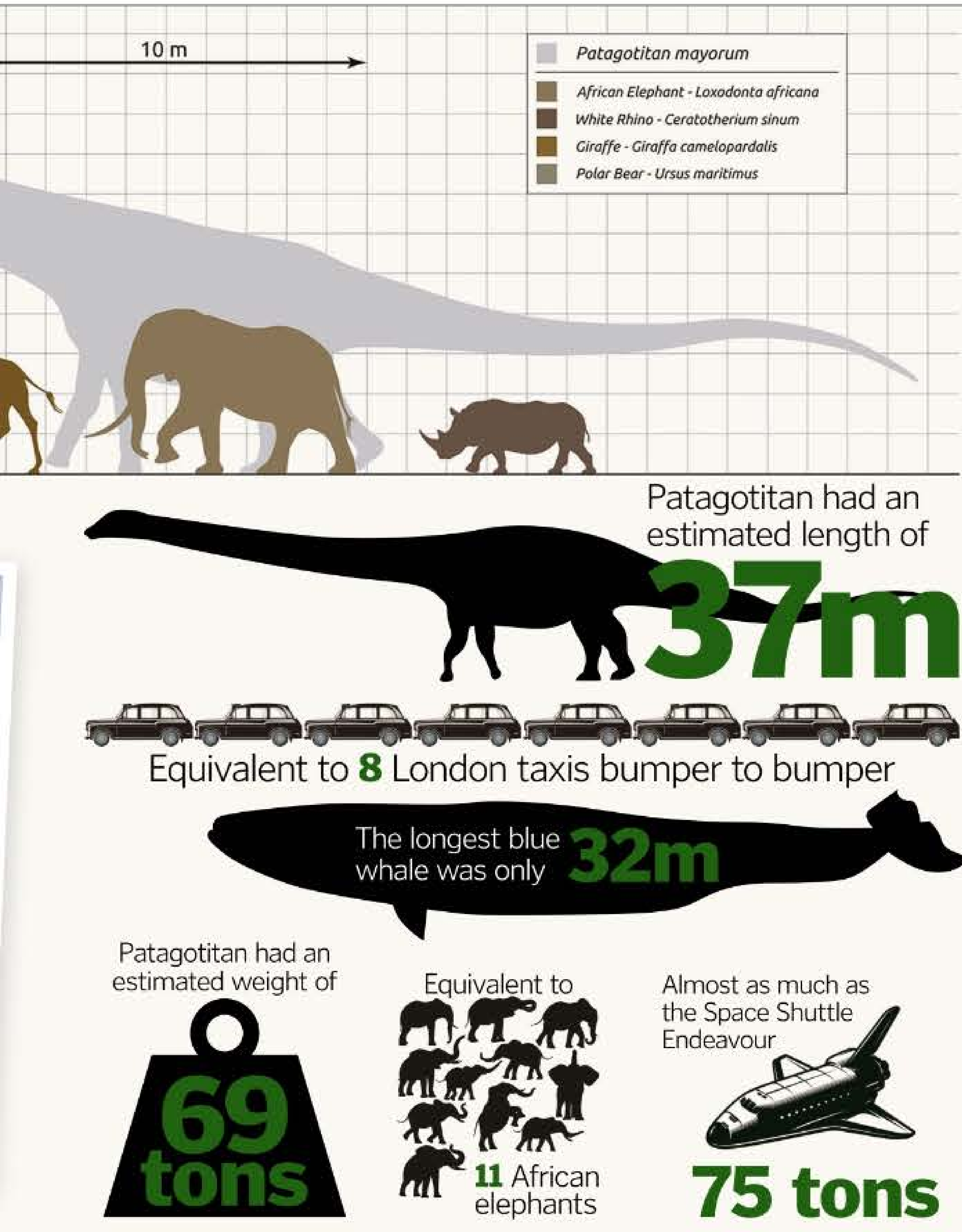
A GARGANTUAN GROUP

Dominating the land when the first examples of flowering plants began to bloom, these behemoths walked among giants. Patagotitan fossils have been dated back to around 100 million years ago, but they're not the only example of giant dinosaurs; this class of the titans includes multiple examples of towering dinosaurs. Even the smallest of the Sauropods, the Saltasaurs, weighed in at around seven tons.

Previously believed to have been the largest of the group, the argentinosaurus is estimated to have weighed around 70 tons. There is a limited amount of fossil evidence to completely reconstruct a argentinosaurus, so the patagotitan is thought to be the largest animal ever due to the greater number of preserved anatomical fossils found.

THE FAMILY NAME

Placing species on the 'tree of life' takes time — four years in the case of the *Patagotitan mayorum*. Previously generalised simply as the Titanosaur, the dinosaur's new name pays



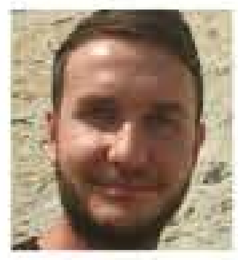
tribute to the location of its discovery (Patagonia) and the Greek work for large ('titan'). The name 'mayorum', however, honours the name of the family that hosted the researchers during their long excavation.

> "Patagotitan fossils have been dated back to around 100 million years ago"

To formally classify a new species with a new name, its lineage must first be identified. Often called the 'tree of life', every known species on Earth filters into different classifications. Using data collected from fossilised remains, palaeontologists can link a species to its prehistoric lineage and determine who's related to whom. The Titanosauria is a diverse clade (group of evolutionary descendants of a common ancestor) of Sauropod dinosaurs that includes some of the largest known land animals to have ever graced the planet.

An expert opinion

Dean Lomax is a multi award-winning palaeontologist, science communicator, TV presenter and author of *Dinosaurs of the British Isles*



How important is this discovery for the field of palaeontology?
Every new fossil find is important as it helps to add a tiny piece to a gigantic prehistoric jigsaw puzzle. The discovery of [the] patagotitan is important in furthering our knowledge of gigantic dinosaurs and the diversity of the group (Titanosauria) it belongs to. The patagotitan is one of the most complete giant dinosaurs known, which helps to 'fill in' the missing pieces of what was previously unknown in other giant Titanosaurs.

For such a huge giant, how much did it need to eat?
To maintain it's huge size the patagotitan would need to have been eating constantly. It's difficult to put any accurate estimate for the amount of vegetation required, but it would certainly have been a huge amount.

What can the evidence of multiple patagotitans tell us?
At least six individual patagotitan specimens were found in the same quarry, although some were found at slightly higher levels, and it is thought that they perished in three different burial events. Clearly it shows that some of these individuals of different size must have been living together in herds.

Why is the name of a new dinosaur species so important?
This is the foundation of palaeontology. The fossil record is very incomplete, especially when we consider that only a tiny percentage of all animals that once lived on the planet have been found as fossils. So describing new species and working out where they fit on the tree of life is important in understanding their place in the history of life in deep time.

How did dinosaurs defend themselves?

Dinosaurs evolved spikes, horns and even thick armoured skin to protect themselves. They needed to be able to fight off predators or risk getting eaten

Herbivorous dinosaurs developed built-in weapons to defend against carnivores. This gave them a better chance of surviving a fight against predators. It also gave them a better chance at defending vulnerable young against predation. Some dinosaurs had sharp claws on their hands, like Iguanodons, which could have been used as a tool and as a weapon. Dinosaurs like Triceratops had horns as long as a human arm that pointed forwards so that the Triceratops could take on its enemy head on. Both these defences could have been used to stab attacking predators.

Other dinosaurs used their tails as weapons. The Ankylosaurus had a heavy, bony hammer at the end of its tail. They could use this to smash into an attacking dinosaur and they were strong enough to crush skulls and break bones. Some dinosaurs were covered in tough scales like a thick coat of armour. Stegosaurus had a row of bony plates running along its spine that are thought to be used for temperature control, though it's certainly possible that they were also used for defence. The bony plates ended along the tail but Stegosaurus remained well defended by the sharp spikes at the end of its tail. Powerful muscles could propel those spikes into an oncoming attacker. Indeed, Allosaurus remains have been found with wounds that line up perfectly with the dimensions of a Stegosaurus's tail spikes

Larger herbivores used their size as a defence. Dinosaurs like the Diplodocus were so massive that carnivores couldn't attack them easily. For smaller dinosaurs, running away was usually the best defence. They developed lighter bones so they could run faster. They needed to escape quickly to avoid fighting altogether.

Tail spikes

Tail spikes could be used as weapons because they were hard and sharp. They also made dinosaurs much harder to eat.

Whip

Dinosaurs like Diplodocus had long tails that they could use like whips. It's possible that they snapped faster than the speed of sound.

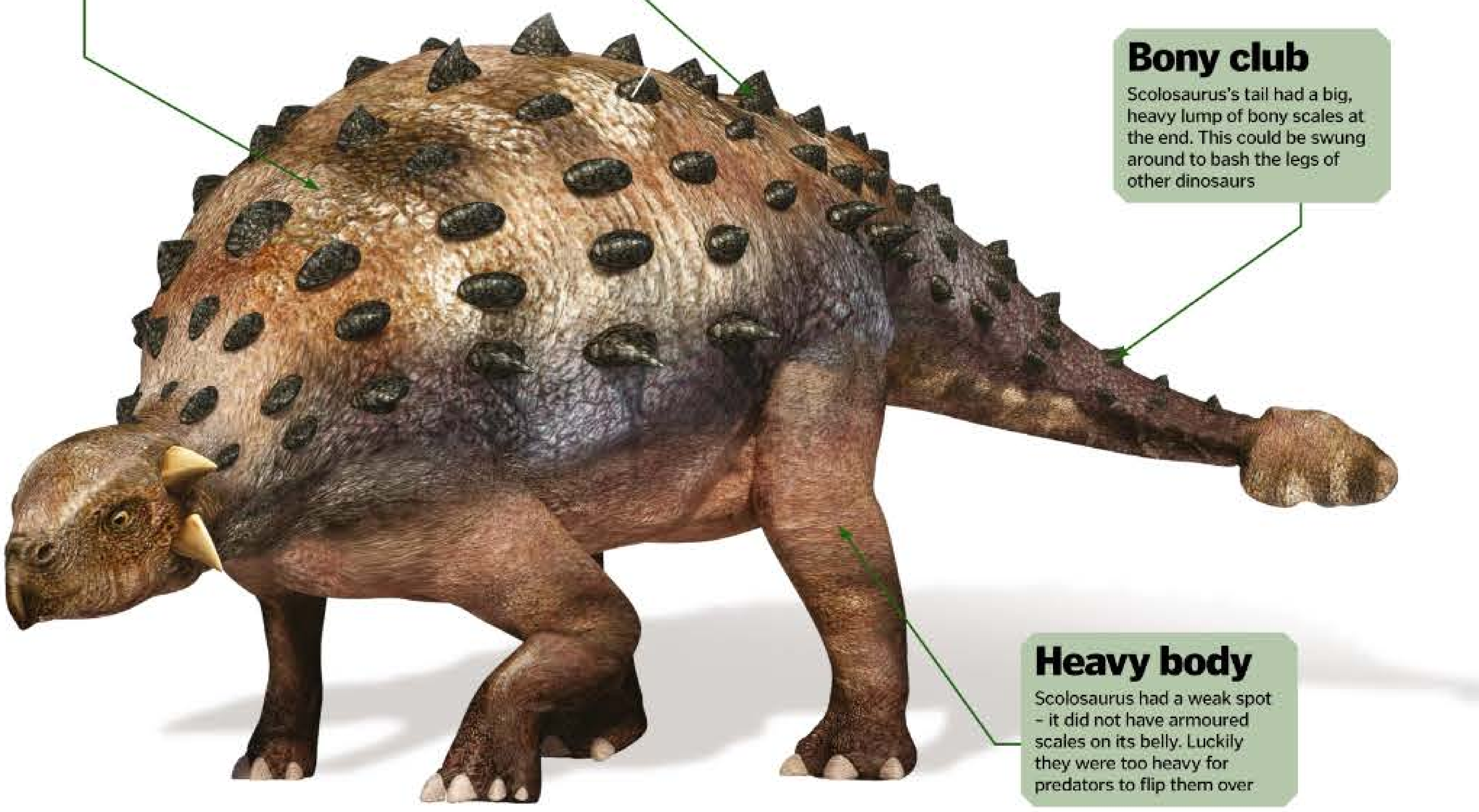
Tail club

Tail clubs were swung around just like a hammer. They were smashed into predators' legs and could crush bones.

Armour plating

The Scolosaurus had a body built for defence - from a bony club at the end of its tail to thick scales covering its body

"Triceratops had pointed horns on its face as long as a human arm"



Thick scales

Scolosaurus's bodies were covered in extra-thick scales that were as hard as bone. Predators had a tough time trying to take a bite out of Scolosaurus

Bony spikes

All along their backs and the tail club were sharp spikes. They could do a lot of damage to any carnivores that got too close

Bony club

Scolosaurus's tail had a big, heavy lump of bony scales at the end. This could be swung around to bash the legs of other dinosaurs

Heavy body

Scolosaurus had a weak spot - it did not have armoured scales on its belly. Luckily they were too heavy for predators to flip them over

Horns

Horned dinosaurs might have charged towards predators to try and scare them away. Their horns could have ripped through skin.

Crest

Head crests were used for communication. Dinosaurs could make warning calls to each other if they saw a predator nearby.

Headbutt

Some dinosaurs, like Stegoceras, could smash skulls with predators. Their heads were protected by shock-absorbing layers of bone

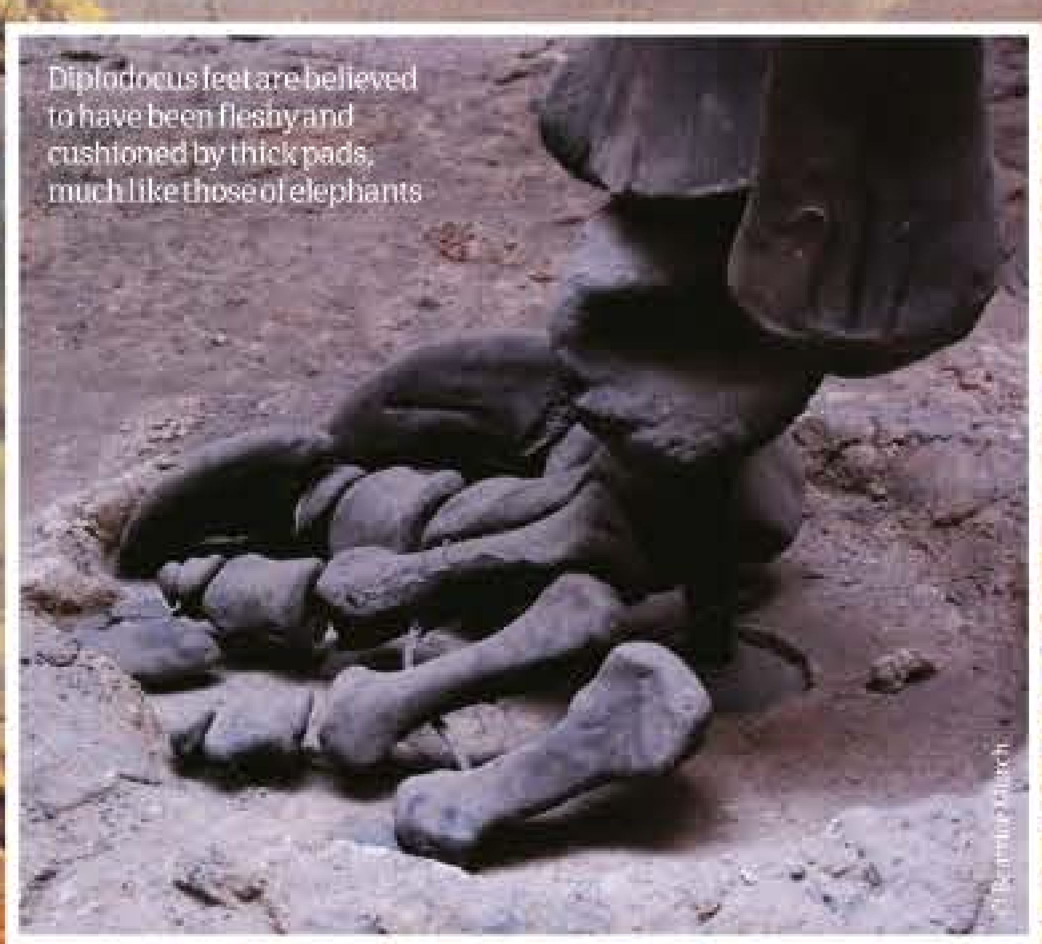
Diplodocus

We find out how this mighty dinosaur once lived

Diplodocus is one of the most famous dinosaurs. It belonged to the group known as the sauropodomorphs and was around in the Late Jurassic period – specifically the Kimmeridgian and Tithonian eras roughly 154-150 million years ago. It reached sizes of up to 25 metres (82 feet) in length and was found in what is now North America. There were four species of Diplodocus, with the largest of these being Seismosaurus, which translates to 'ground shaker'.

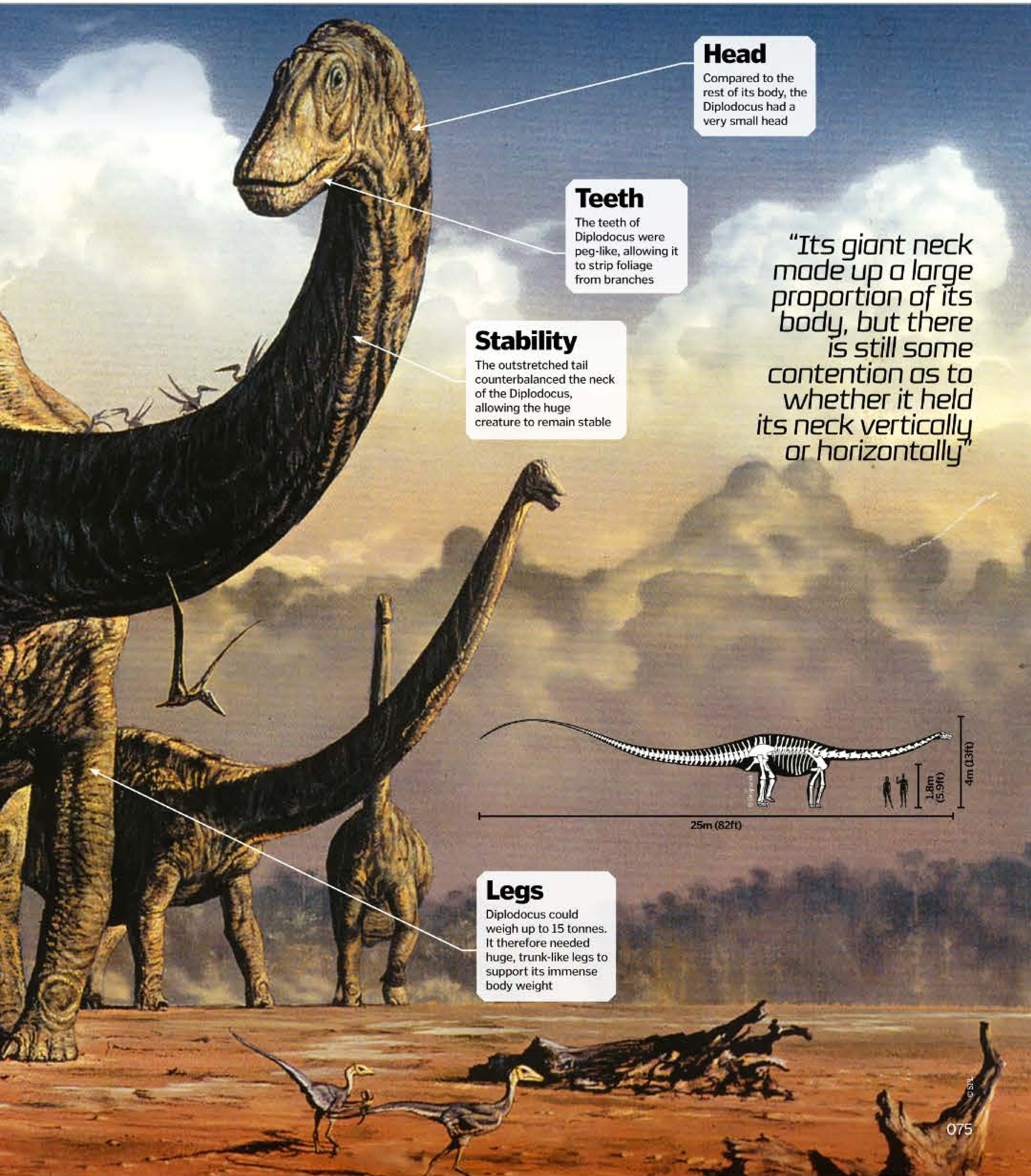
Diplodocus was part of the diplodocid family, sharing the same characteristic of having 15 neck vertebrae, short forelimbs compared to the rest of its body and a whip-like tail. Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally. Its rectangular skull contained huge eye sockets and nasal chambers. Studies of its teeth suggest that Diplodocus fed using what is known as branch stripping, where the branch of a tree is grasped in a creature's jaw and then pulled sharply up or down, tearing off foliage.

Diplodocus was the largest dinosaur around. It was later eclipsed by other sauropods, but it roamed the tallest for at least a few million years. Numerous bones have been found and studied by palaeontologists, providing an insight into how these giant dinosaurs were able to support themselves and how they lived.



Diplodocus feet are believed to have been fleshy and cushioned by thick pads, much like those of elephants

DID YOU KNOW? *The name Diplodocus means 'double beam', a reference to the V-shaped bones in the vertebrae of the tail*



Head

Compared to the rest of its body, the Diplodocus had a very small head

Teeth

The teeth of Diplodocus were peg-like, allowing it to strip foliage from branches

Stability

The outstretched tail counterbalanced the neck of the Diplodocus, allowing the huge creature to remain stable

"Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally"

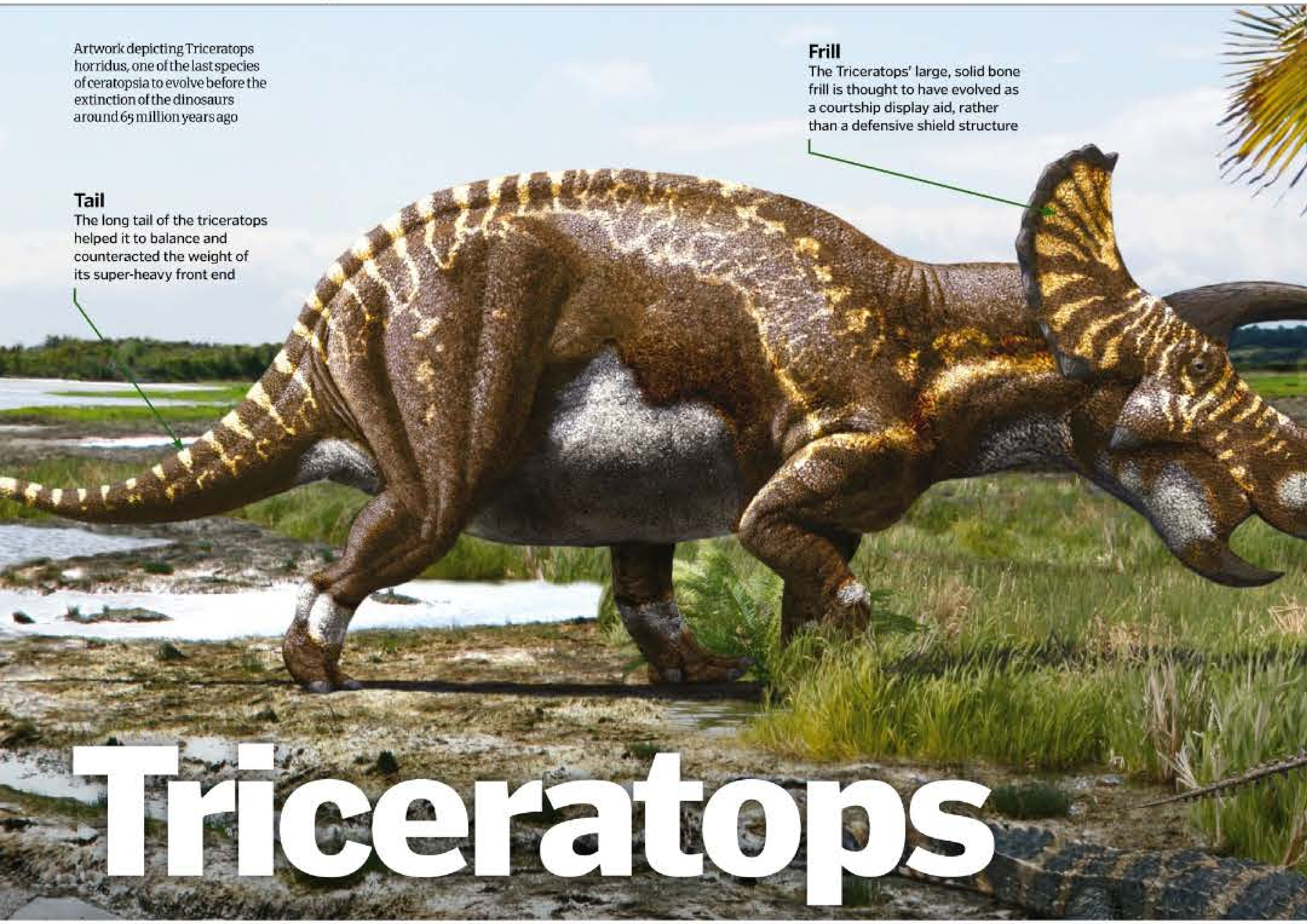
4m (13ft)

1.8m (5.9ft)

25m (82ft)

Legs

Diplodocus could weigh up to 15 tonnes. It therefore needed huge, trunk-like legs to support its immense body weight



Artwork depicting Triceratops horridus, one of the last species of ceratopsia to evolve before the extinction of the dinosaurs around 65 million years ago

Triceratops

One of the most well-known dinosaurs, the Triceratops was a herbivorous titan that was very well equipped for a fight

Triceratops is a genus of herbivorous dinosaur that comprises two validated species – Triceratops horridus and Triceratops prorsus, both of which roamed Earth during the Late Cretaceous period (68-65 Ma) before being eradicated in the K-T mass-extinction event that wiped out all dinosaurs.

Triceratops were large, rhinoceros-like animals that weighed many tonnes – a fully grown adult would be expected to weigh in the region of seven tonnes. They were heavily armoured with reinforced bone horns, which could exceed 70 centimetres (28 inches) and a solid bone frill, and hugely powerful thanks to their sturdy frame. These traits, combined, made both species of Triceratops a fearsome foe to potential predators, capable of puncturing flesh and shattering bone with their sharp horns when charging.

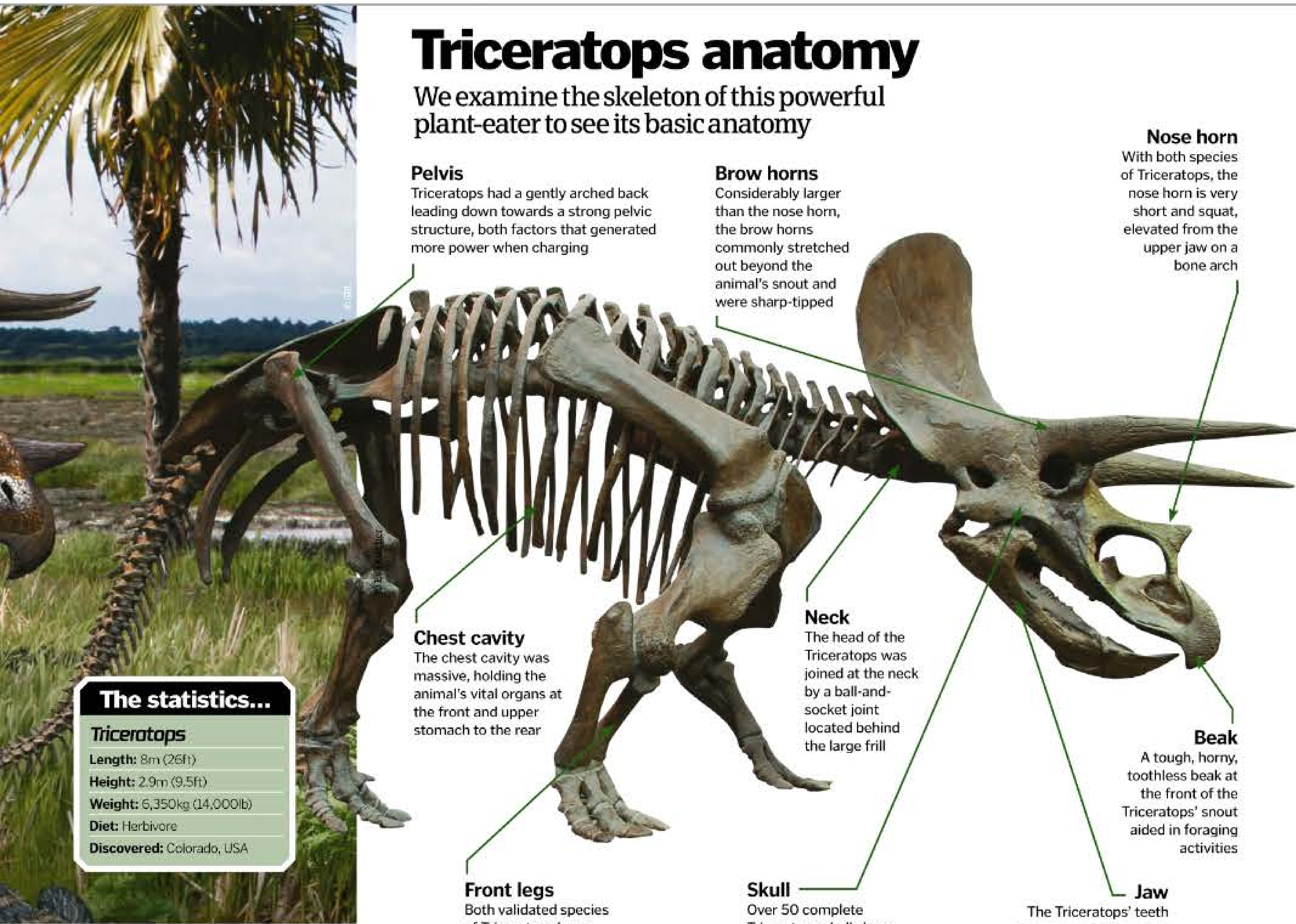
In terms of anatomy (for a comprehensive rundown, see the 'Triceratops anatomy' illustration), the Triceratops genus is incredibly interesting, not least because many of its parts' functions are still debated today in the field of palaeontology. A good example of this can be seen by analysing a typical Triceratops skull, which – aside from typically measuring a whopping two metres (6.6 feet) in length – sported three horns as well as a fluted, extravagant rear frill.

The horns, from which the genus gets its name, and frill have been successfully argued by palaeontologists to have been used for self-defence against predators, with close examination of unearthed specimens revealing battle scars, cuts, punctures and cracks. However, modern scholars also postulate that both skull features, along with the elongated nature of the skull itself, most likely also evolved as courtship aids, with potential mates selected on the size and shape of these features. It has also been suggested that the frill may have helped Triceratops regulate their body temperature in a similar manner to the plate-laden Stegosaurus (whose name translates as roof, or covered, lizard).

Other anatomical areas of interest lie in this dinosaur's large bird-like beak and hips. Indeed, it is because of these particular features that this genus has been used as a reference point in the definition of all dinosaurs – ie all dinosaurs are descendants of the most recent common ancestor of Triceratops and, as such, this common ancestor is also that of birds prevalent throughout the world today. It's important to note here that modern birds did not descend from triceratops directly, but rather from its common ancestor with all other dinosaurs; today's birds in fact originate from saurischian dinosaurs.

Triceratops anatomy

We examine the skeleton of this powerful plant-eater to see its basic anatomy



Pelvis
Triceratops had a gently arched back leading down towards a strong pelvic structure, both factors that generated more power when charging

Brow horns
Considerably larger than the nose horn, the brow horns commonly stretched out beyond the animal's snout and were sharp-tipped

Nose horn
With both species of Triceratops, the nose horn is very short and squat, elevated from the upper jaw on a bone arch

Chest cavity
The chest cavity was massive, holding the animal's vital organs at the front and upper stomach to the rear

Neck
The head of the Triceratops was joined at the neck by a ball-and-socket joint located behind the large frill

Beak
A tough, horny, toothless beak at the front of the Triceratops' snout aided in foraging activities

Front legs
Both validated species of Triceratops have extremely sturdy front legs to ensure support for its heavy head and chest cavity

Skull
Over 50 complete Triceratops skulls have been found today, each confirming that they were incredibly heavy and solid

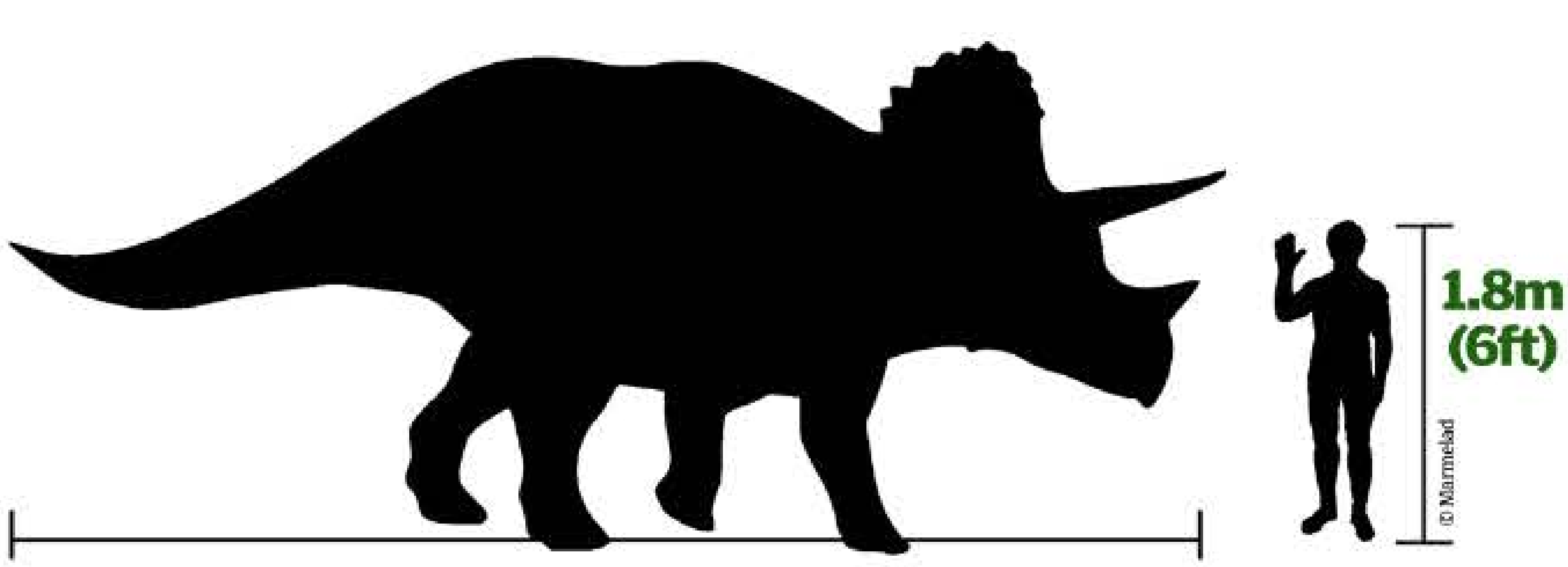
Jaw
The Triceratops' teeth were arranged in groups of 36-40 columns in each side of the jaw, with three to five stacked teeth per column

The statistics...

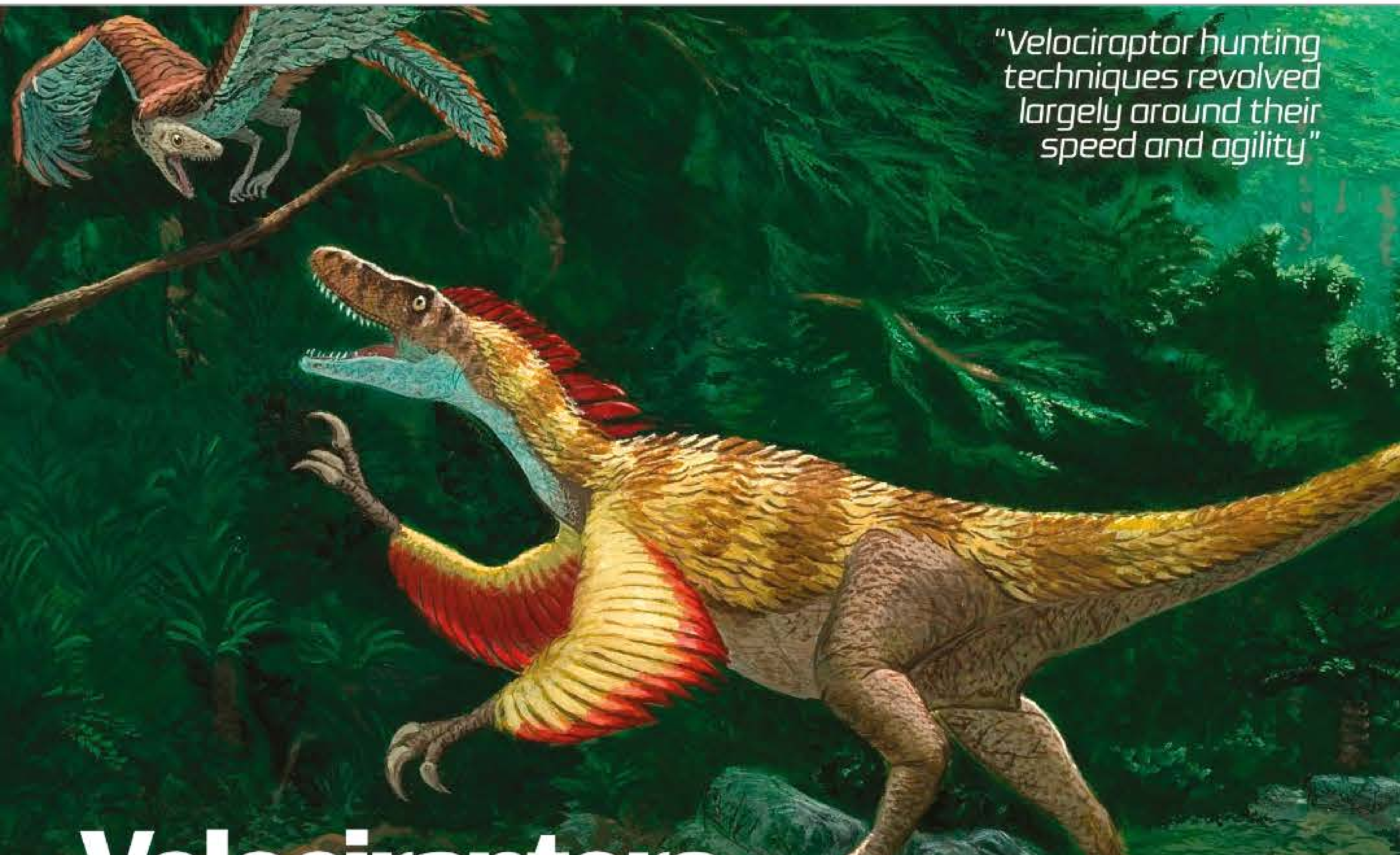
Triceratops
Length: 8m (26ft)
Height: 2.9m (9.5ft)
Weight: 6,350kg (14,000lb)
Diet: Herbivore
Discovered: Colorado, USA

The fundamental diet of the Triceratops was largely dictated by – and most likely co-evolved with – its low-slung posture and head position, which was located close to the ground. As a consequence of these factors, as well as its deep and narrow beak and sharp teeth batteries, both species of Triceratops most likely consumed large amounts of low-growth ferns, palms and cycads, plucking the plants with their beaks and then shredding the fibrous material with their teeth.

The Triceratops' main potential predators were carnivorous theropod dinosaurs such as the Tyrannosaurus rex. However, while modern-day depictions of these two prehistoric titans are often far-fetched, Triceratops specimens have been discovered with T-rex bite marks and even one where the herbivore had had one of its brow horns snapped off entirely.



8-9m (26-30ft)



Velociraptors

One of the most deadly dinosaurs, the Velociraptor was an adept predator and scavenger, but not quite the creature Hollywood would have us believe…

Velociraptors have been ingrained in public consciousness since the 1993 movie *Jurassic Park* showcased them as the most fearsome of apex predators. Smart, lethal and bloodthirsty, the Velociraptors of the film arguably stole the show. However, the movie was famed for its indulgence of artistic licence, with palaeontologists bemoaning the lack of historical accuracy.

So what were these dinosaurs really like? Velociraptor, of which there are two verified species – V mongoliensis and V osmolskae, was a genus of dromaeosaurid ("running lizard") theropod dinosaur that lived in the Late Cretaceous period, about 75-71 million years ago. They were two metres (6.6 feet) long, just under a metre (three feet) high, feathered and bipedal, running on two of their three toes per foot. Velociraptors were native to modern-day central Asia (most notably Mongolia), where they built large, ground-based nests to protect clutches of their vulnerable young.

Velociraptors, though often living in close proximity to one another, were largely solitary and, while certain finds suggest they could have teamed up while chasing their quarry, they were not pack hunters, with evidence showing they would fight among themselves for feeding rights. In addition, their staple diet consisted of animals of equal size and weight to themselves or those smaller than them, with very little evidence suggesting they would attempt to bring down larger dinosaurs, such as the Tyrannosaurus rex.

Velociraptor hunting techniques revolved largely around their speed and agility. They could accelerate up to 64 kilometres (40 miles) per hour and pounce long distances, as well as grip prey firmly with their unique, sickle-shaped claws (notably their enlarged 'killing claw'). These traits were partnered with a tendency to ambush prey, rather than tackle their victims face on or from long range (see the 'Slash or subdue?' boxout for more). Interestingly, however, while there's no doubt that Velociraptors hunted live prey, unearthed fossilised evidence suggests they were also incredibly active scavengers, with the species frequently feeding on carrion (pterosaur bones have been found in velociraptor guts, for instance) and carcasses left over by other predators.

Velociraptors died out along with the remaining species of dromaeosauridae in the run up to, and as a result of, the Cretaceous-Tertiary mass-extinction event that occurred approximately 65.5 million years ago. Despite this, elements of their anatomy and appearance can still be seen today – albeit in heavily evolved forms – in many species of bird.

The statistics...

Velociraptor

Length: 2m (6.6ft)
Height: 0.8m (2.5ft)
Weight: 113kg (200lb)
Diet: Carnivore
Discovered: Mongolia

This is an accurate representation of a Velociraptor, being covered in feathers and attacking prey smaller than itself

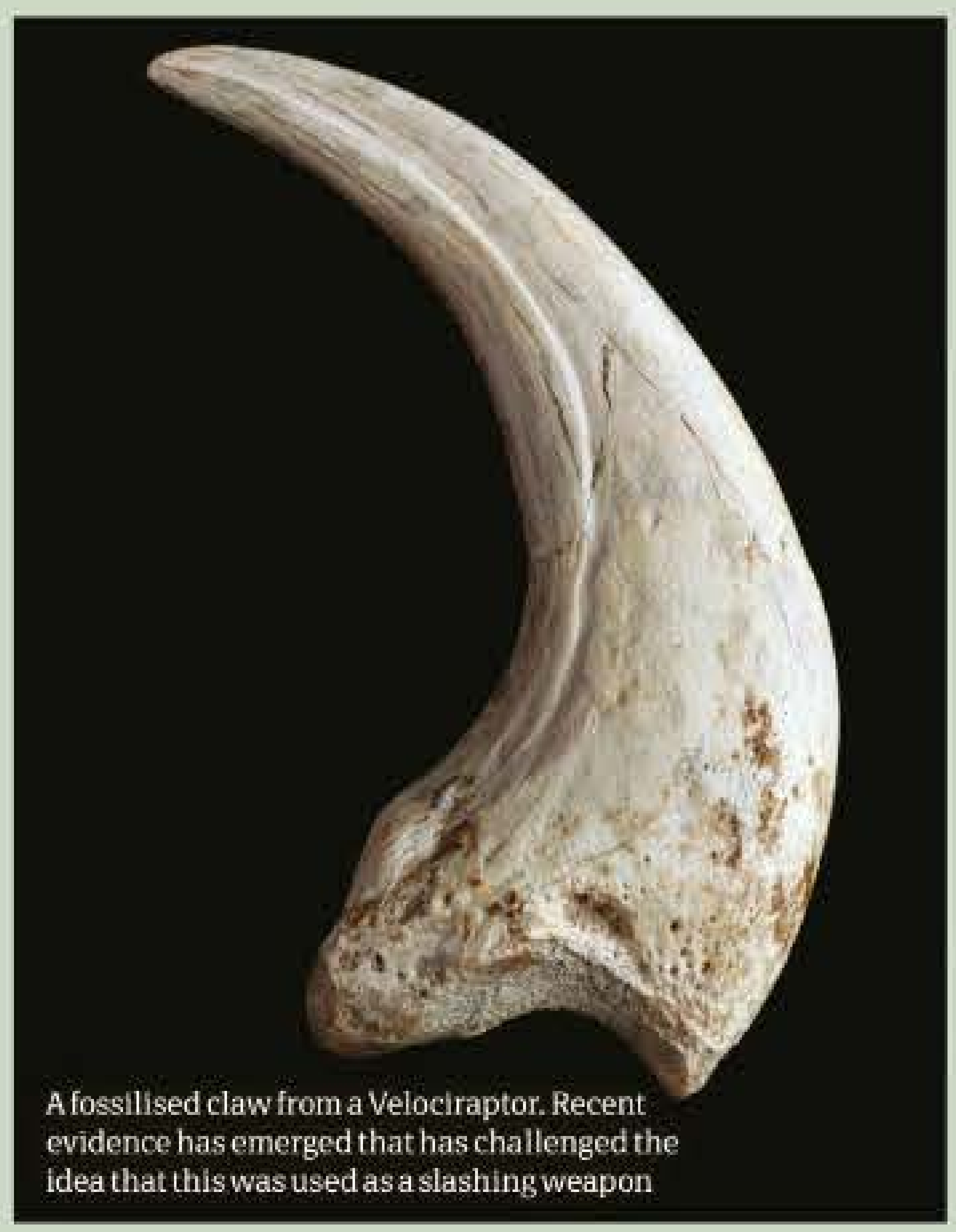
Slash or subdue?

Did Velociraptors use their sickle-shaped claws to disembowel prey or for some other purpose?

The majority of non-avian theropod dinosaurs are characterised by razor-sharp serrated teeth and talon-like recurved claws, the Velociraptor being no exception. Armed with a bounty of claws on both its hands and feet, the Velociraptor at first glance seems to be the perfect killing machine, capable of rapidly chasing down prey before shredding their flesh with one of their knife-like tools. Well, that was at least the commonly accepted theory among palaeontologists until late in 2011, before a new study by a team of international dinosaur experts suggested an entirely different use for them.

The study suggested that far from their claws – specifically the Velociraptor's much-touted 'killing claws' – being used to shred and slice prey in order to kill them prior to consumption, they were far more likely to be used in a similar way to the talons of modern-day hawks and eagles. This entails the birds using their talons as a gripping tool, snaring prey of a lesser body size, pinning them down with their own body weight and then often consuming them live with their beaks.

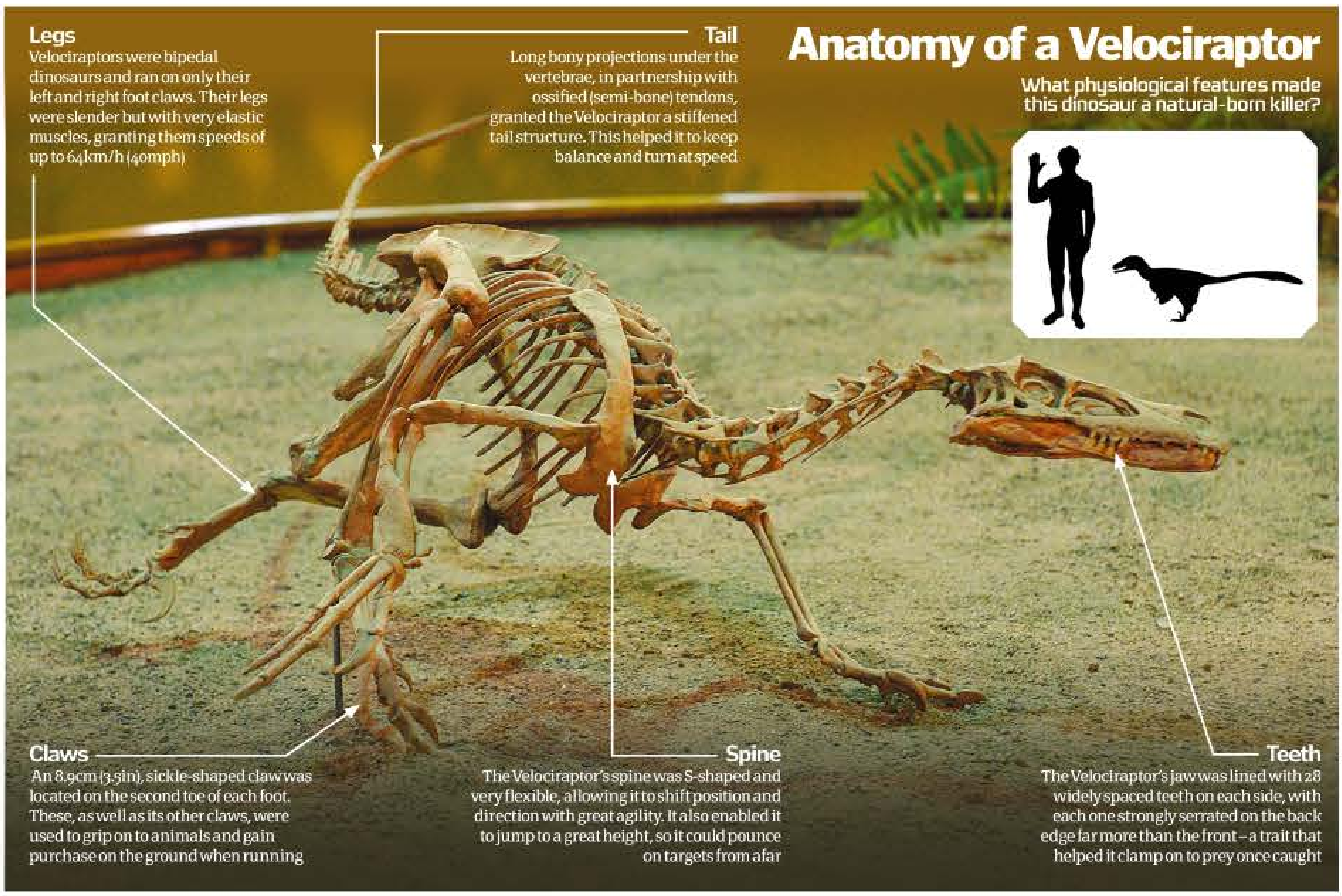
This theory is seemingly backed up by the Velociraptor's feet showing morphology consistent with a grasping function, supporting a prey immobilisation model rather than the originally assumed combative one.



A fossilised claw from a Velociraptor. Recent evidence has emerged that has challenged the idea that this was used as a slashing weapon

Anatomy of a Velociraptor

What physiological features made this dinosaur a natural-born killer?



Legs
Velociraptors were bipedal dinosaurs and ran on only their left and right foot claws. Their legs were slender but with very elastic muscles, granting them speeds of up to 64km/h (40mph)

Tail
Long bony projections under the vertebrae, in partnership with ossified (semi-bone) tendons, granted the Velociraptor a stiffened tail structure. This helped it to keep balance and turn at speed

Claws
An 8.9cm (3.5in), sickle-shaped claw was located on the second toe of each foot. These, as well as its other claws, were used to grip on to animals and gain purchase on the ground when running

Spine
The Velociraptor's spine was S-shaped and very flexible, allowing it to shift position and direction with great agility. It also enabled it to jump to a great height, so it could pounce on targets from afar

Teeth
The Velociraptor's jaw was lined with 28 widely spaced teeth on each side, with each one strongly serrated on the back edge far more than the front – a trait that helped it clamp on to prey once caught

The bony plates along the Stegosaurus's back were probably used for display rather than as a form of defence

The statistics...

Stegosaurus

Length: 8-9m (26.2-29.5ft)
Height: 2.8-4m (9.2-13.1ft)
Weight: 3,100kg (6,800lb)
Diet: Herbivore
Discovered: Colorado, USA

Stegosaurus

One of the best-known of all the dinosaurs, the Stegosaurus boasted a series of diamond-shaped bone plates and a tail that could kill

Skull
Despite its large scale, the Stegosaurus's head was very narrow and it had a tiny brain capacity

Maybe the most iconic genus of dinosaurs ever excavated, the Stegosaurus was a herbivorous titan, capable of consuming huge quantities of low-level foliage while protecting itself from predators with its vast armoured frame and potentially lethal spiked tail.

The first example of Stegosaurus – from which its family name, Stegosauridae, derived – was unearthed in 1877 and since then four confirmed species of the dinosaur have been officially identified. Each species demonstrates a similar structure and feature set, with each animal epitomising a large quadruped, sporting a series of diamond-shaped plates along its back. These large creatures were over eight metres (26 feet) long and were heavily built at over 3,000 kilograms (6,614 pounds).

Interestingly, it's these plates that palaeontologists and academics know the least about, with a variety of arrangements, structures and uses suggested. When first unearthed it was speculated that they were used as a form of armoured defence against carnivorous predators. However, their positioning along the back and apparent bluntness has led to this theory being largely dismissed today. Instead, academics suggest that the plates were used as a decorative feature – perhaps in mating displays or to ward off Stegosaurus rivals in territory disputes.

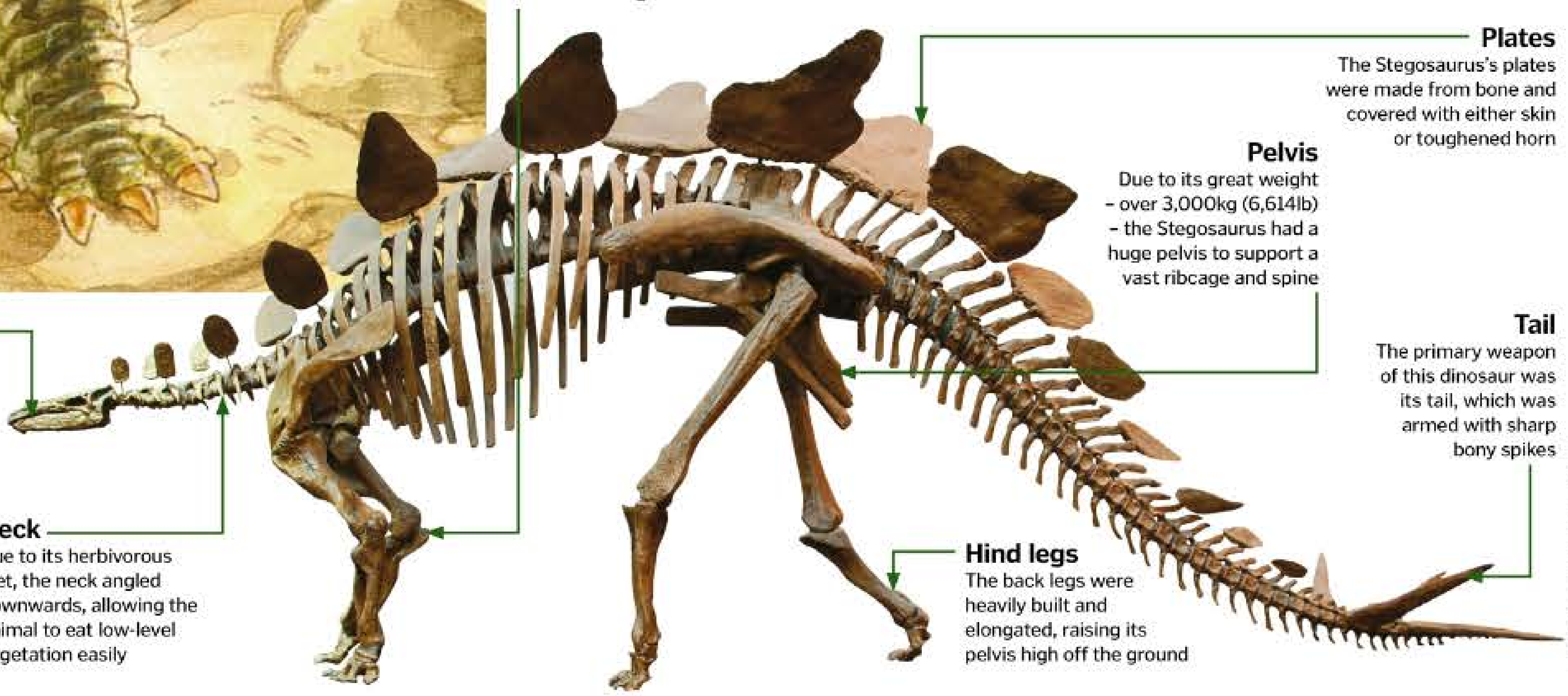
The field of palaeobiology reveals almost everything else about this genus. Studying fossilised evidence it is clear that due to Stegosaurus's very small and narrow skull, they had a tiny brain and so were not very intelligent – something seemingly confirmed by their primitive and mundane feeding habits. The low level of the animal's neck, short but bulky forelegs and raised pelvis/elongated hind legs indicate that Stegosaurus spent much of its daily routine consuming large quantities of low-lying foliage (such as ferns, cycads and conifers). This is confirmed by the shape and formation of its teeth and a low bite force.

Upon closer inspection of the dinosaur's legs it is also clear that it could not move very quickly. This is apparent as the discrepancy in size between the front and hind legs is so great that, if the creature ran at over eight kilometres (five miles) per hour, its longer back legs would cross over the forelegs leading it to fall.

Despite these shortcomings, Stegosaurus wasn't totally defenceless, as it boasted a flexible, armour-plated and spiked tail. Taking Stegosaurus stenops as an example, the dinosaur had four dermal tail spikes of approximately 75 centimetres (29.5 inches) in length each, which extended out from the tail slightly off the horizontal plane. These spikes enabled the Stegosaurus to whip its tail and puncture the flesh of any attackers.

Stegosaurus anatomy

Understand the biological structure of this distinctive dino from the inside out



The statistics...

Tyrannosaurus rex	
Length:	12-13m (40-43ft)
Height:	4m (13ft)
Weight:	6-9 tonnes
Diet:	Carnivore
Discovered:	Colorado, USA

Tyrannosaurus rex

Learn about the lizard king's physiology and how it presided over the prehistoric jungle

Tyrannosaurus rex was a species of Theropoda dinosaur in the Late Cretaceous period. Like other tyrannosaurids – such as Tarbosaurus and Gorgosaurus – the T-rex was a bipedal carnivore and apex predator and scavenger, preying on smaller dinosaurs directly or out-muscling them for their kills. Typical prey included hadrosaurs and ceratopsians.

Tyrannosaurus rex's name translates as "tyrant lizard king" – something that was historically attributed due to its immense size. Indeed, the Tyrannosaurus rex is one of the largest species ever excavated by palaeontologists, with specimens averaging over 12 metres (40 feet) in length and four metres (13 feet) in height, but it wasn't the biggest carnivorous dino. It was incredibly heavy with fully grown adults weighing up to nine tonnes; this figure was suggested in 2011 after an in-depth study which made digital 3D models of five T-rex skeletons.

Due to its considerable size, the Tyrannosaurus rex had very few, if any, predators – a fact that enabled it to remain unchallenged as the Late Cretaceous era's apex predator on land and to live for lengthy periods. Estimates taken from excavated specimens – of which there are now more than 30 confirmed around the world – indicate that the T-rex's life span was roughly 30 years, with the majority of growth taking place in the first 16 years before tailing off rapidly. This suggests that the Tyrannosaurus rex would have reached adulthood at approximately 20 years of age.

As with almost all species of Dinosauria, the Tyrannosaurus was wiped out 65.5 million years ago in the Cretaceous-Tertiary (K-T) extinction event. At the time it was one of the last widespread non-avian dinosaurs, as evidenced by the discovery of many specimens throughout North America.

"Due to its considerable size, the Tyrannosaurus rex had very few, if any, predators"

T-rex mythbuster

Due to a variety of films depicting the T-rex in their own unique way, an accurate view of the species has been clouded. For example, despite being a prominent star of all the *Jurassic Park* films, Tyrannosaurus rex did not exist in the Jurassic period (199-145 MYA). In fact, it lived millions of years later during the Late Cretaceous (100-65.5 MYA). Further, for decades T-rex has been depicted as having green scaly skin. However, recent evidence suggests its skin colour was varied and, during the early years of its life, it probably sported insulative feathers. The T-rex has also been commonly lauded as the biggest carnivorous dinosaur of them all. This isn't strictly true, with palaeontological evidence suggesting the species Spinosaurus outsized it by over three metres (9.9 feet) in length. And finally, another myth perpetuated in *Jurassic Park* is that the Tyrannosaurus could run at high speed (ie keep up with a car), but it could probably only manage about 40 kilometres (25 miles) per hour due to its relatively small strides.

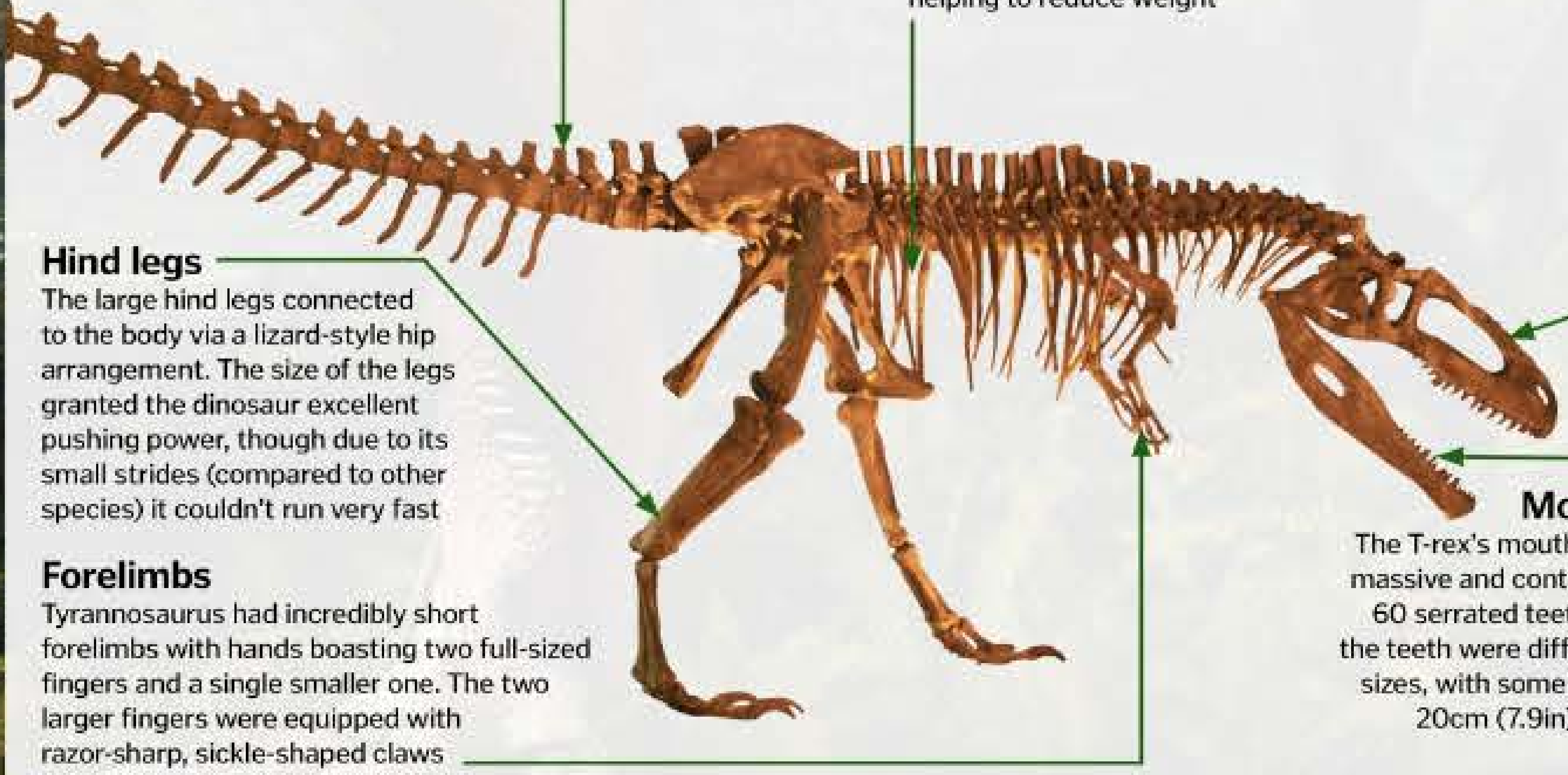
Anatomy of the lizard king

We analyse a Tyrannosaurus rex's skeleton to see what made it such a deadly predator

Tail
Crucial for maintaining balance – especially as modern evidence suggests T-rex had a near-horizontal spinal position – the dinosaur's large tail was essential for chasing prey

Body cavity
The Tyrannosaurus rex had an incredibly heavy body structure and a wide body cavity. To improve mobility, some of the dinosaur's vertebrae had holes – helping to reduce weight

Skull
Tyrannosaurus's skull was huge and its snout and lower jaw were very deep. The eye sockets faced forward to a greater degree than most dinosaurs, indicating it had acute binocular vision



Hind legs
The large hind legs connected to the body via a lizard-style hip arrangement. The size of the legs granted the dinosaur excellent pushing power, though due to its small strides (compared to other species) it couldn't run very fast

Forelimbs
Tyrannosaurus had incredibly short forelimbs with hands boasting two full-sized fingers and a single smaller one. The two larger fingers were equipped with razor-sharp, sickle-shaped claws

Mouth
The T-rex's mouth was massive and contained 60 serrated teeth. All the teeth were different sizes, with some up to 20cm (7.9in) long

The giant Brachiosaurus

Three times longer and twice as tall as a double-decker bus, Brachiosaurus truly was a terrestrial titan of epic proportions

Brachiosaurus was a genus of sauropod dinosaur that roamed the Earth during the Late Jurassic period (circa 155-140 million years ago). They are characterised, like many sauropods of the time, by their huge necks and comparatively tiny skulls and brains. Currently only one species has been officially confirmed – B altithorax – though others have been suggested.

Interestingly, like other sauropods, these creatures – despite weighing an estimated 60 tons and measuring up to 30 metres (98 feet) long – were actually colossal vegetarians, with their diet comprising solely foliage.

Their evolution of such a long neck (see 'The high life' boxout for more details) seems to be intrinsically linked to their diet, with the elevated head position enabling them to access leaves unavailable to shorter species.

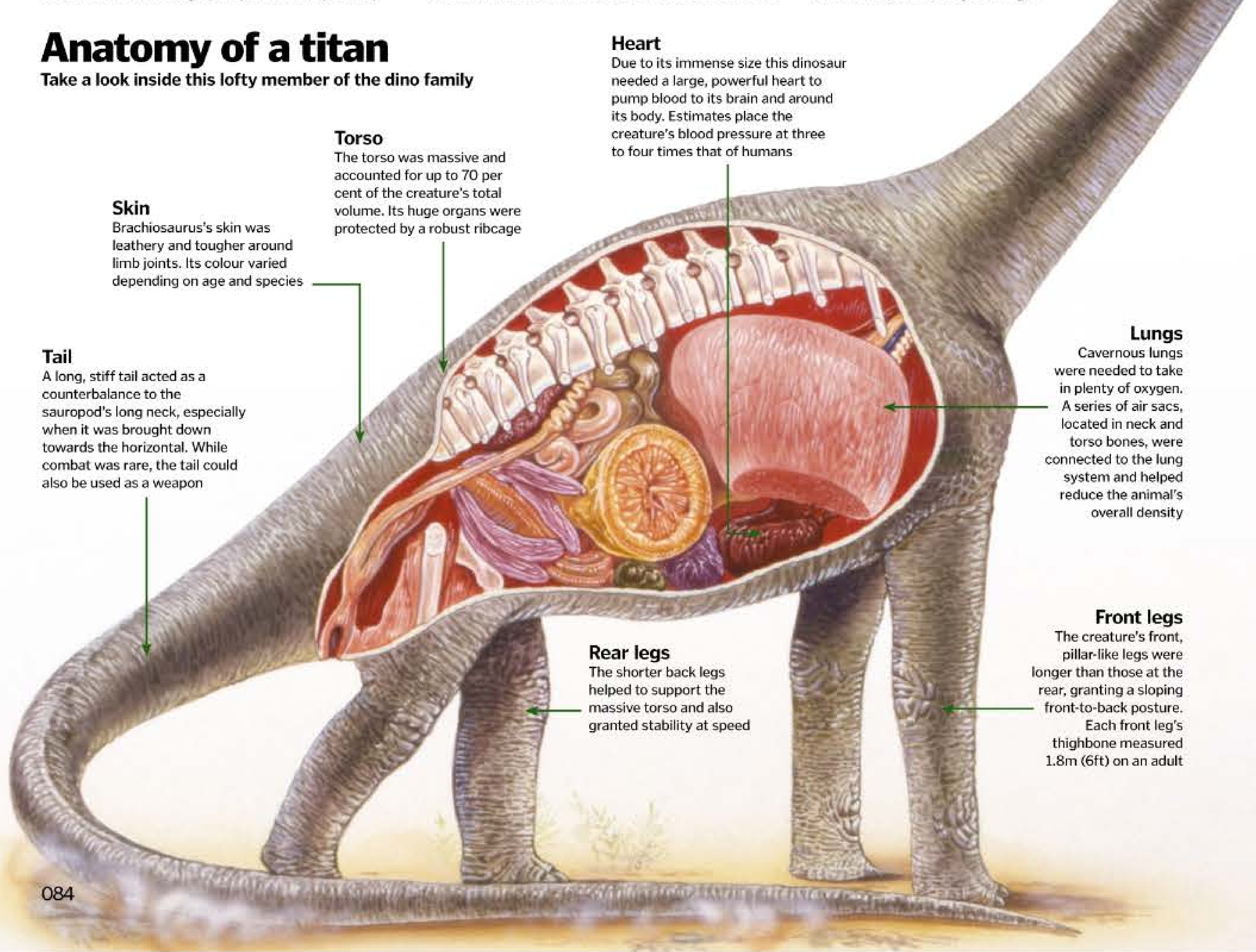
This dominion over a food source is also a major factor behind their generally massive proportions, with millions of years of domination allowing them to grow to sizes far in excess of rival creatures from the same era.

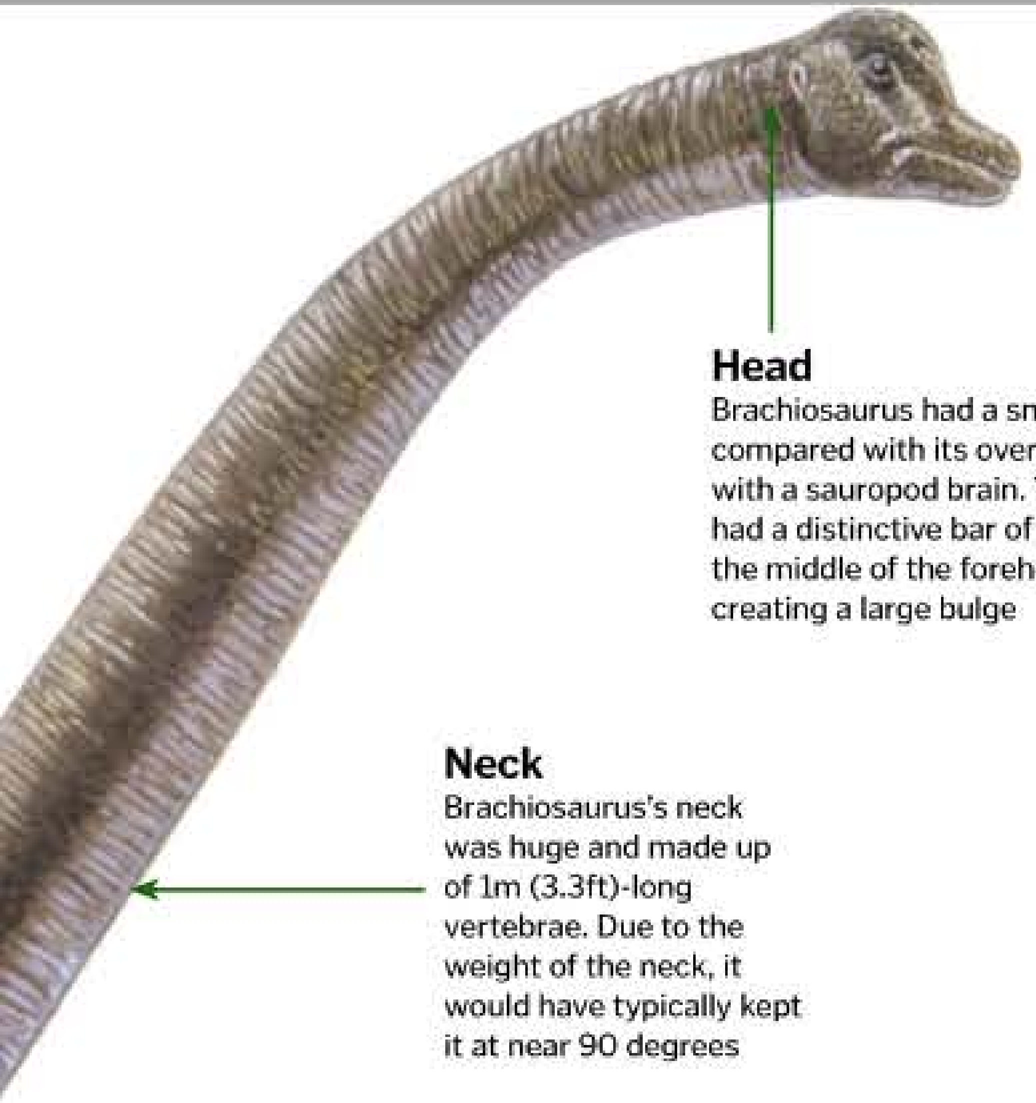
The epic size of Brachiosaurus was also its primary form of defence when it came to predators. Once fully grown, their legs would have resembled tree trunks and these – partnered with a heavy, stocky tail – made them extremely difficult to tackle.

While their size and domination granted many benefits, it was also a contributor to Brachiosaurus's eventual demise, with resource depletion and climate change leading to their background extinction around 145 million years ago.

Anatomy of a titan

Take a look inside this lofty member of the dino family

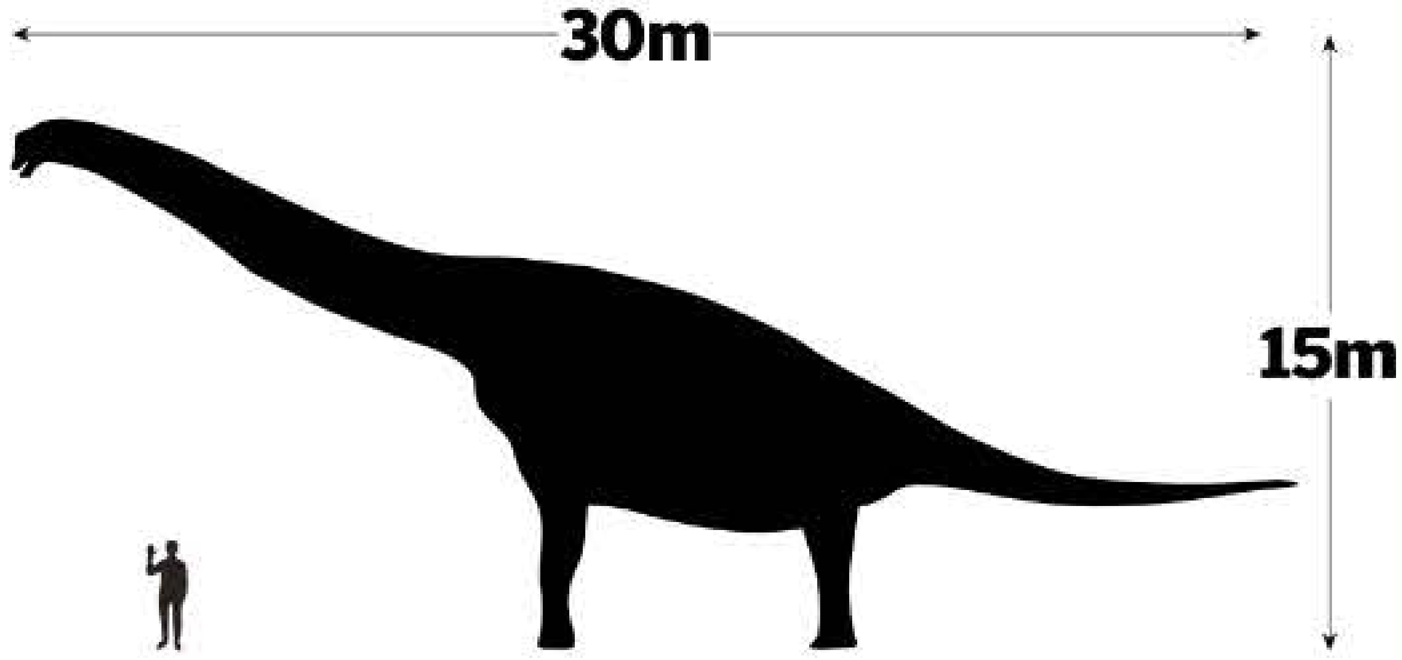


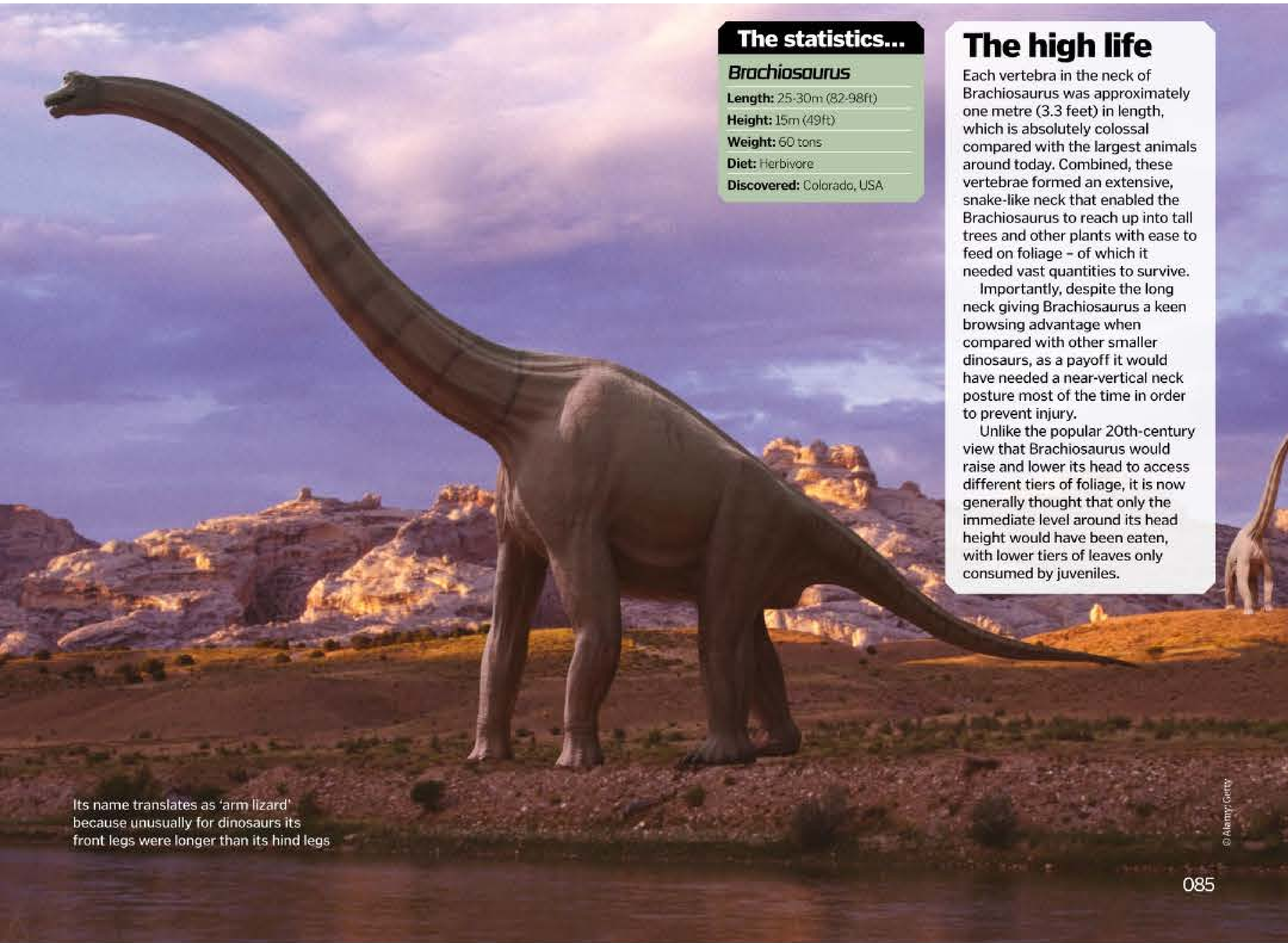


Head
Brachiosaurus had a small head compared with its overall size, with a sauropod brain. The skull had a distinctive bar of bone in the middle of the forehead, creating a large bulge

Neck
Brachiosaurus's neck was huge and made up of 1m (3.3ft)-long vertebrae. Due to the weight of the neck, it would have typically kept it at near 90 degrees

Brachiosaurus vs human
How does this mega-dino size up to your average Homo sapien?





The statistics...
Brachiosaurus

Length: 25-30m (82-98ft)
Height: 15m (49ft)
Weight: 60 tons
Diet: Herbivore
Discovered: Colorado, USA

The high life
Each vertebra in the neck of Brachiosaurus was approximately one metre (3.3 feet) in length, which is absolutely colossal compared with the largest animals around today. Combined, these vertebrae formed an extensive, snake-like neck that enabled the Brachiosaurus to reach up into tall trees and other plants with ease to feed on foliage – of which it needed vast quantities to survive.

Importantly, despite the long neck giving Brachiosaurus a keen browsing advantage when compared with other smaller dinosaurs, as a payoff it would have needed a near-vertical neck posture most of the time in order to prevent injury.

Unlike the popular 20th-century view that Brachiosaurus would raise and lower its head to access different tiers of foliage, it is now generally thought that only the immediate level around its head height would have been eaten, with lower tiers of leaves only consumed by juveniles.

Its name translates as 'arm lizard' because unusually for dinosaurs its front legs were longer than its hind legs

Ankylosaurus

A club-wielding brute of a creature, this tough dino had the power to break bones

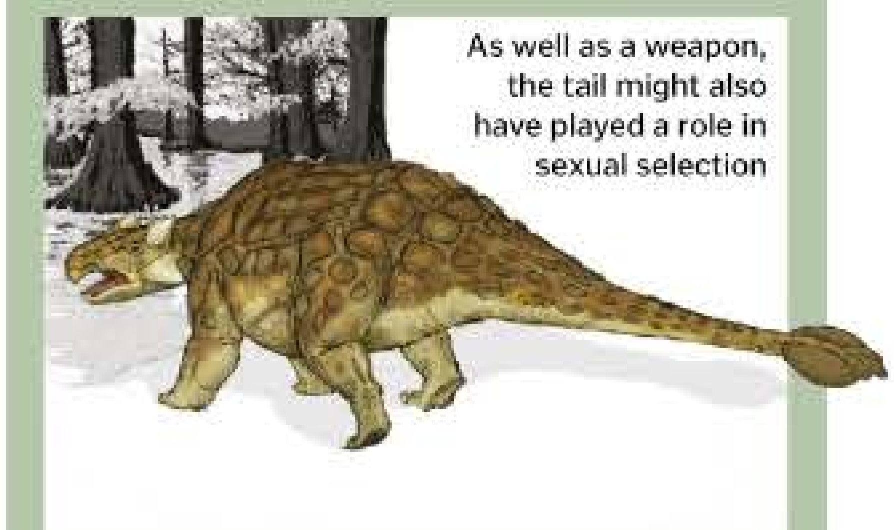
Ankylosaurus was one of the largest ankylosaurs, a genus of armoured dinosaurs that lived throughout North America between 75 and 65.5 million years ago. Famous for both its brutal tail-mounted club and its immense bone plate armour, the Ankylosaurus was a defensive titan, capable of fending off rivals many times its size.

Ankylosaurus's focus on defence was born out of its herbivorous nature, with its entire body geared towards the consumption of foliage. From its low-slung body, rows of leaf-shaped cropping teeth, short front legs, wide feet and cavernous stomach, the Ankylosaurus was the consummate browser, devouring vegetation whole with little shredding or chewing. Indeed, studies have indicated that the skull and jaw of the Ankylosaurus were structurally tougher than many similar, contemporary dinosaurs.

In fact, evidence suggests that Ankylosaurus – and ankylosaurs in general – were adept survivors. But despite their impressive armour, weaponry and sustainable diet, they could not cope with the Cretaceous-Tertiary extinction event that wiped out all terrestrial dinosaurs approximately 65.5 million years ago. Only a few fossils of this prehistoric herbivore have been excavated to date – most coming from the Hell Creek Formation in Montana, USA.

Club members only

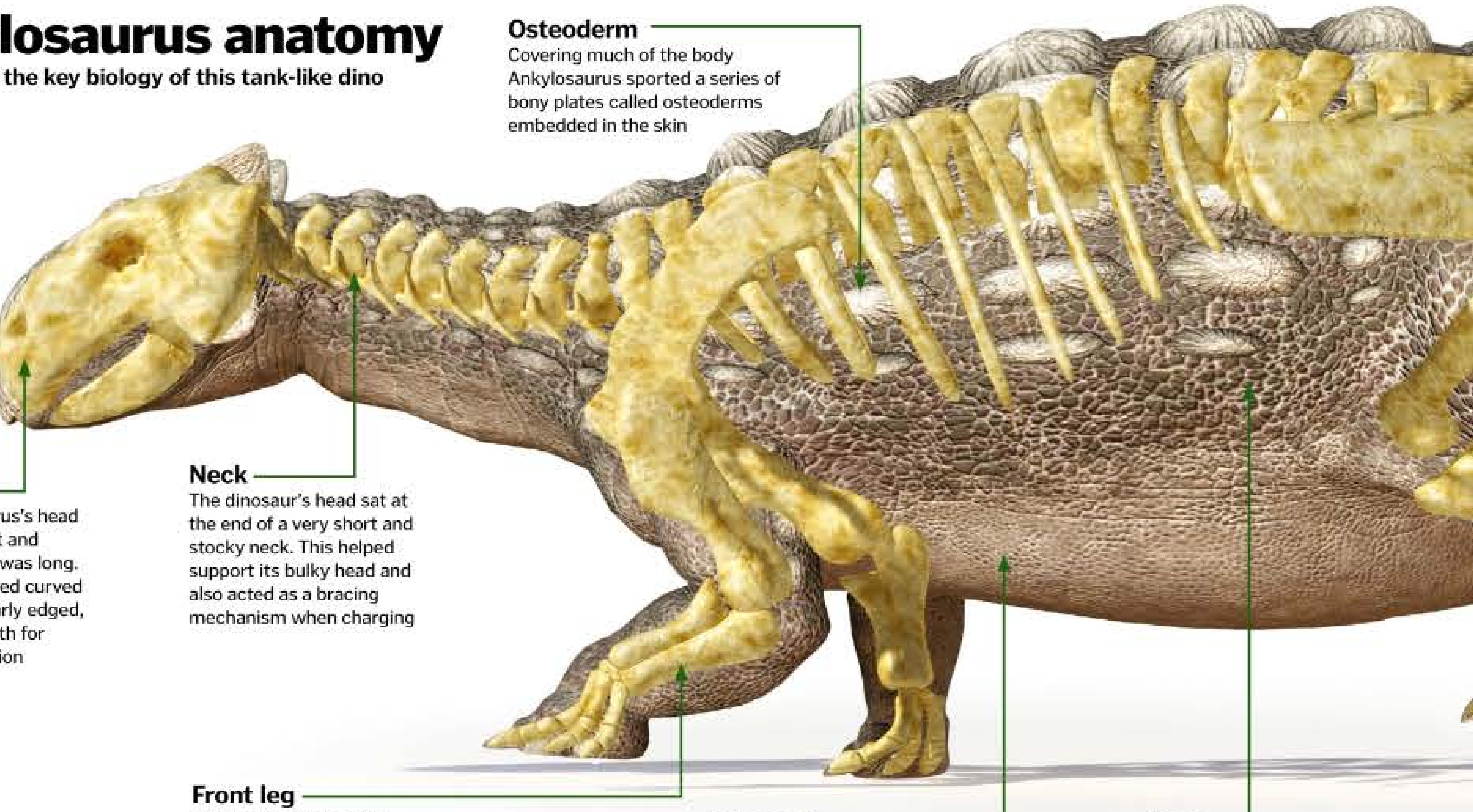
The well-known tail club of the Ankylosaurus was one of the most lethal weapons sported by any dinosaur. The club was made from several large bone plates called osteoderms that were fused into the last few vertebrae of the animal's tail. Behind these vertebrae several others lined with thick, partially ossified tendons completed the club's handle, resulting in a structure that, when swung, was capable of dealing out a lot of damage. Indeed, a study in 2009 suggested that the tail clubs of fully grown ankylosaurs could easily crush and break bone with a force capable of caving in an assailant's skull. Whether or not the animal purposely aimed the club to cause damage remains unclear at this point.



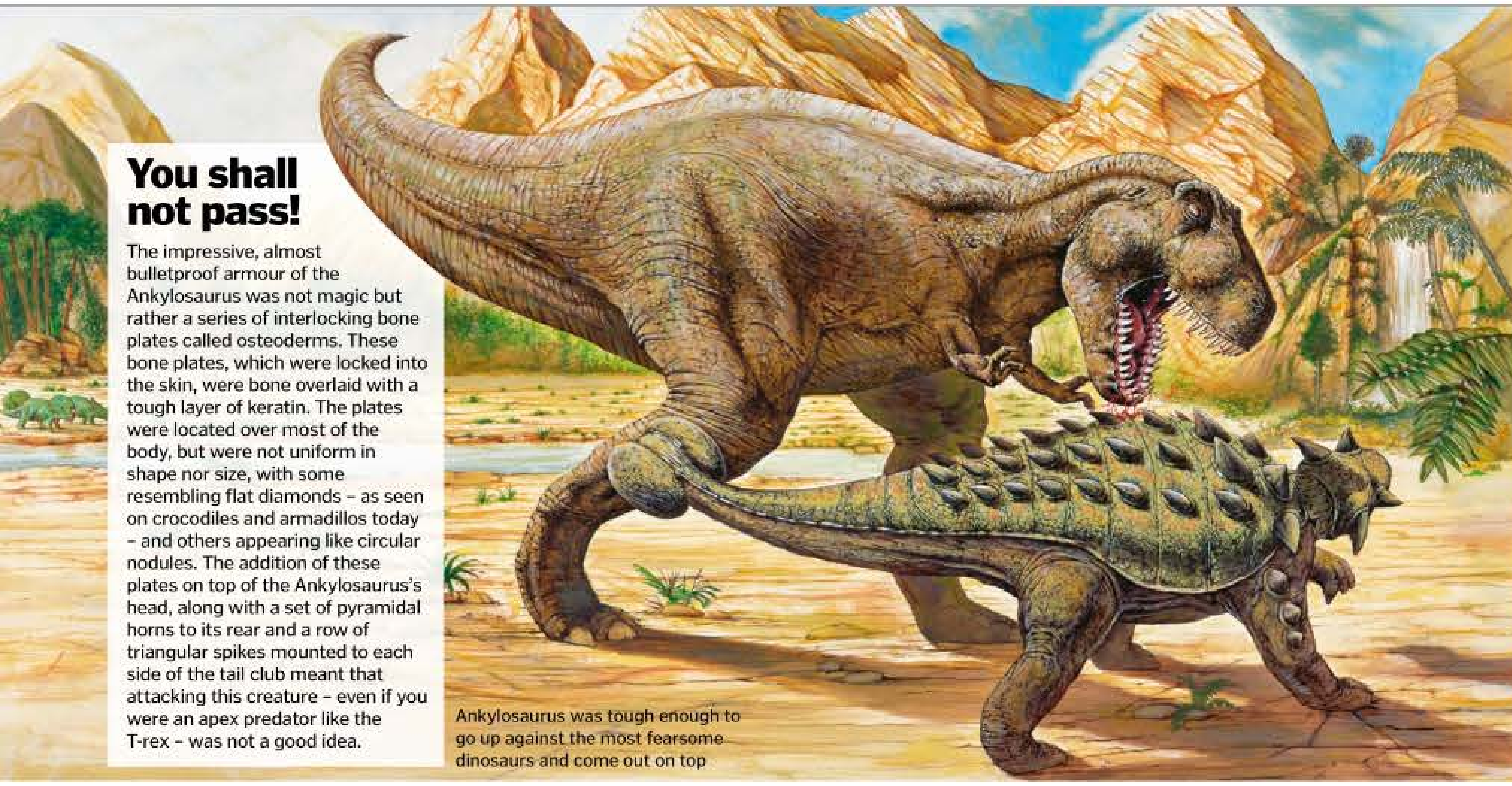
As well as a weapon, the tail might also have played a role in sexual selection

Ankylosaurus anatomy

Get to know the key biology of this tank-like dino



DID YOU KNOW? *Interestingly the earliest specimens of ankylosaurs we have found did not possess a tail club*

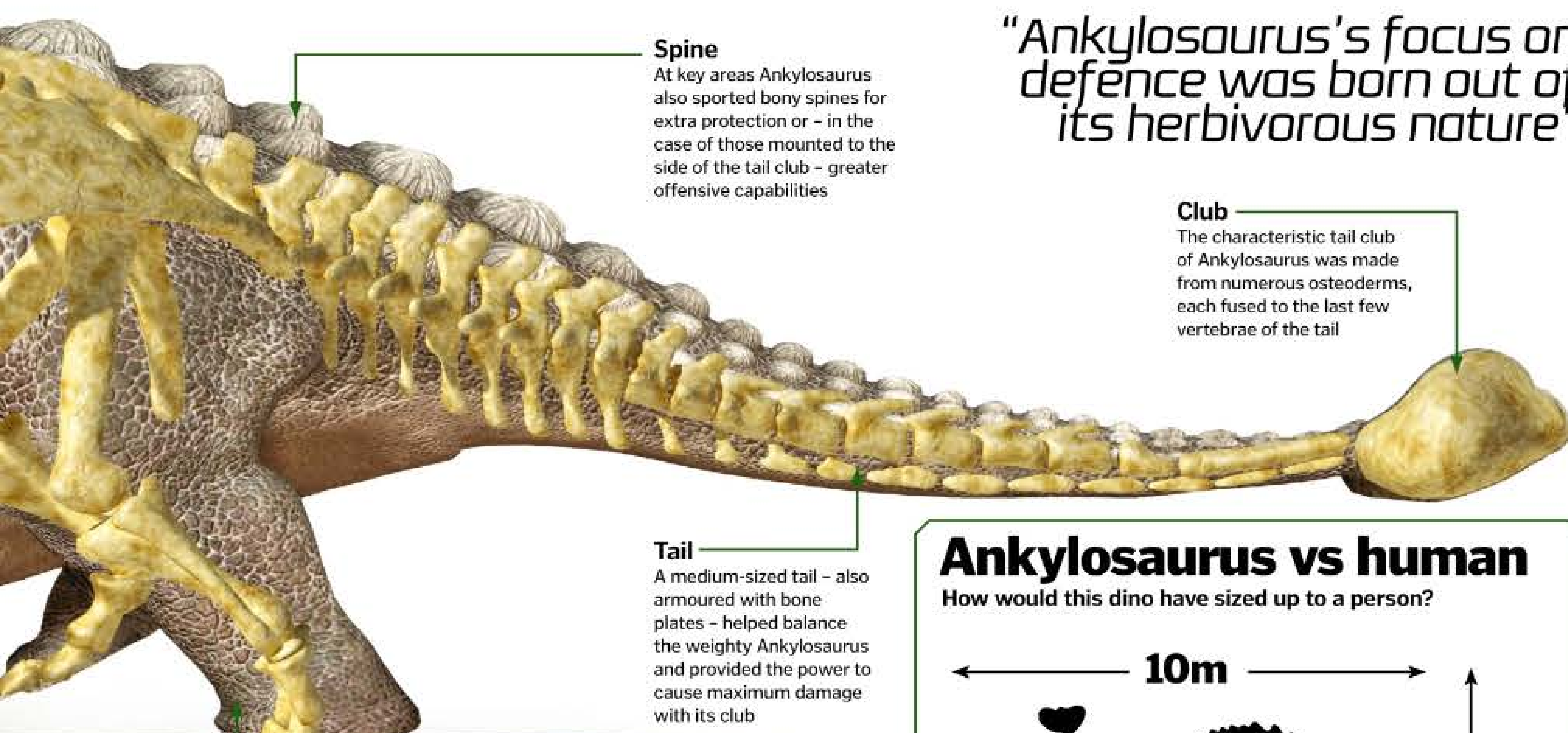


You shall not pass!

The impressive, almost bulletproof armour of the Ankylosaurus was not magic but rather a series of interlocking bone plates called osteoderms. These bone plates, which were locked into the skin, were bone overlaid with a tough layer of keratin. The plates were located over most of the body, but were not uniform in shape nor size, with some resembling flat diamonds – as seen on crocodiles and armadillos today – and others appearing like circular nodules. The addition of these plates on top of the Ankylosaurus's head, along with a set of pyramidal horns to its rear and a row of triangular spikes mounted to each side of the tail club meant that attacking this creature – even if you were an apex predator like the T-rex – was not a good idea.

Ankylosaurus was tough enough to go up against the most fearsome dinosaurs and come out on top

"Ankylosaurus's focus on defence was born out of its herbivorous nature"



Spine
At key areas Ankylosaurus also sported bony spines for extra protection or – in the case of those mounted to the side of the tail club – greater offensive capabilities

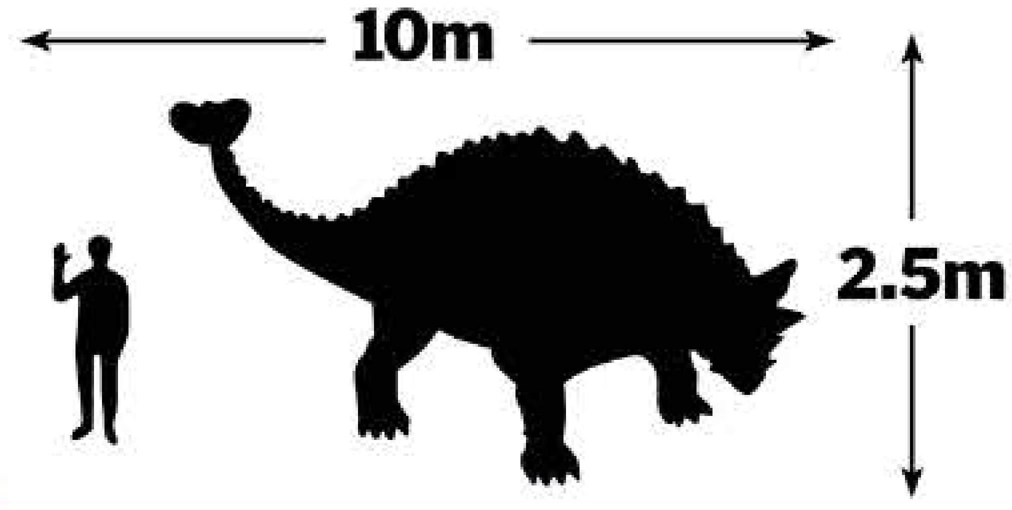
Club
The characteristic tail club of Ankylosaurus was made from numerous osteoderms, each fused to the last few vertebrae of the tail

Tail
A medium-sized tail – also armoured with bone plates – helped balance the weighty Ankylosaurus and provided the power to cause maximum damage with its club

Rear leg
Equally powerful – if not more so – but longer than the Ankylosaurus's forelegs, the rear legs reached up to about 1.7m (5.6ft) at the hip

Ankylosaurus vs human

How would this dino have sized up to a person?



Meet the real Brontosaurus

One of the largest animals to ever exist on Earth, the Apatosaurus towered metres over its Jurassic rivals

Around four times heavier than an African elephant, five times longer than your car and almost six times the height of a full-grown human, Apatosaurus was one of the largest dinosaurs of the Jurassic era and one of most gigantic to ever walk the Earth.

As is typical with large dinosaurs of this period, Apatosaurus (once mistakenly known as Brontosaurus) was a herbivore, consuming vast quantities of foliage and grasses over the lands that now form modern-day North America. Interestingly, despite its size, its name is derived from the Greek 'apate' and 'saurus', which translate as 'deception lizard' – a name bestowed by its original discoverer, American palaeontologist Othniel Charles Marsh.

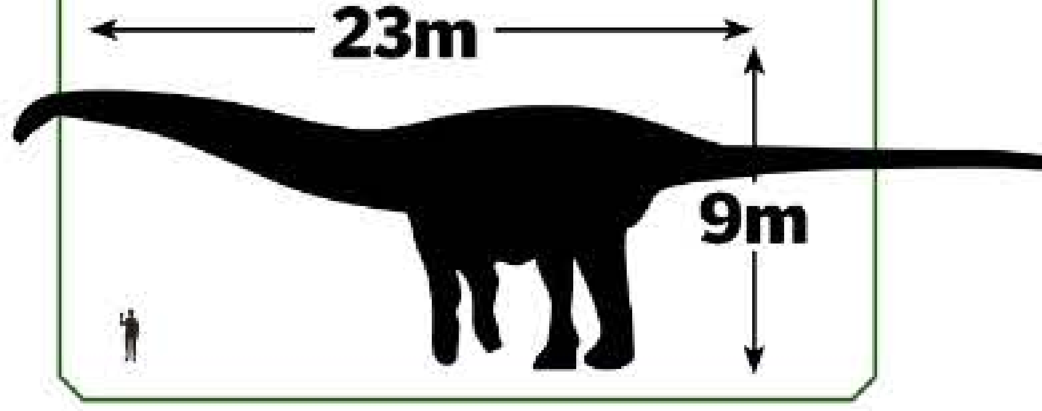
Prior to the 1970s, Apatosaurus, along with many other sauropods, were considered largely aquatic creatures that relied on being partially submerged in swamps and lakes to remain stable – a view seemingly confirmed by their colossal bulk. However, recent evidence has demonstrated that through a combination of massive limb bones and a series of weight-reducing internal air sacs located throughout the neck and spine, Apatosaurus's home was, in fact, entirely land-based, only spending time at water sources to drink.

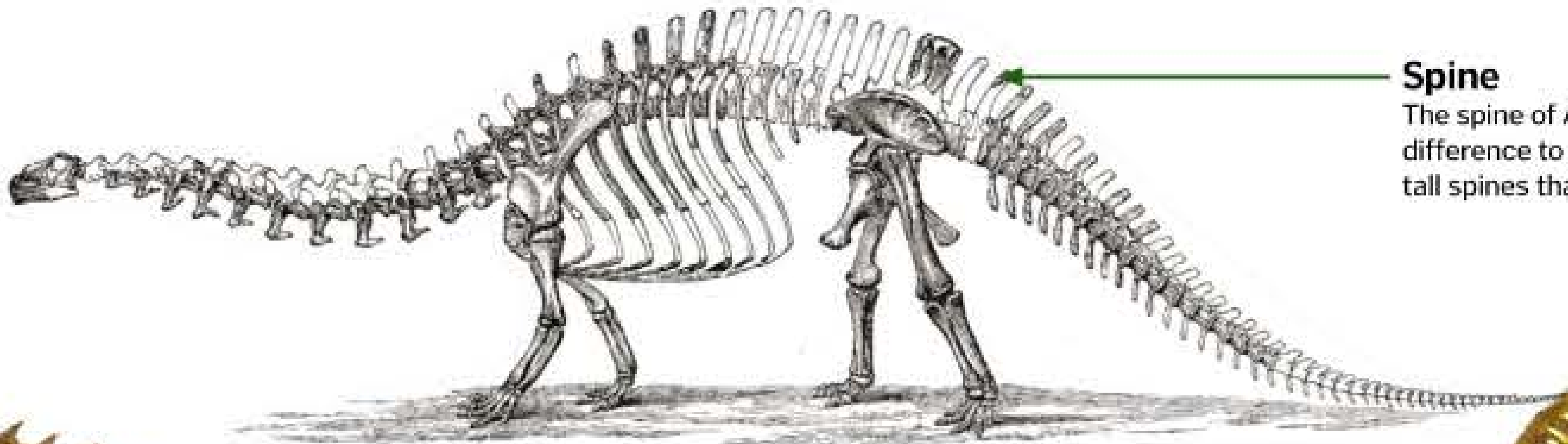
Speaking of drinking, the Apatosaurus required gallons of water per day to remain healthy, while it also needed to process vast amounts of food, spending a large proportion of each day grazing. It did this with few predators, as only the largest carnivorous dinosaurs had any chance of bringing down an Apatosaurus, largely thanks to its size. It also had a deadly weapon in its tail, which was capable of being swung at great velocity at any foes.

Despite its defensive prowess, however, the Apatosaurus could not battle off extinction, with it falling to a medium-sized extinction event around 150 million years ago.

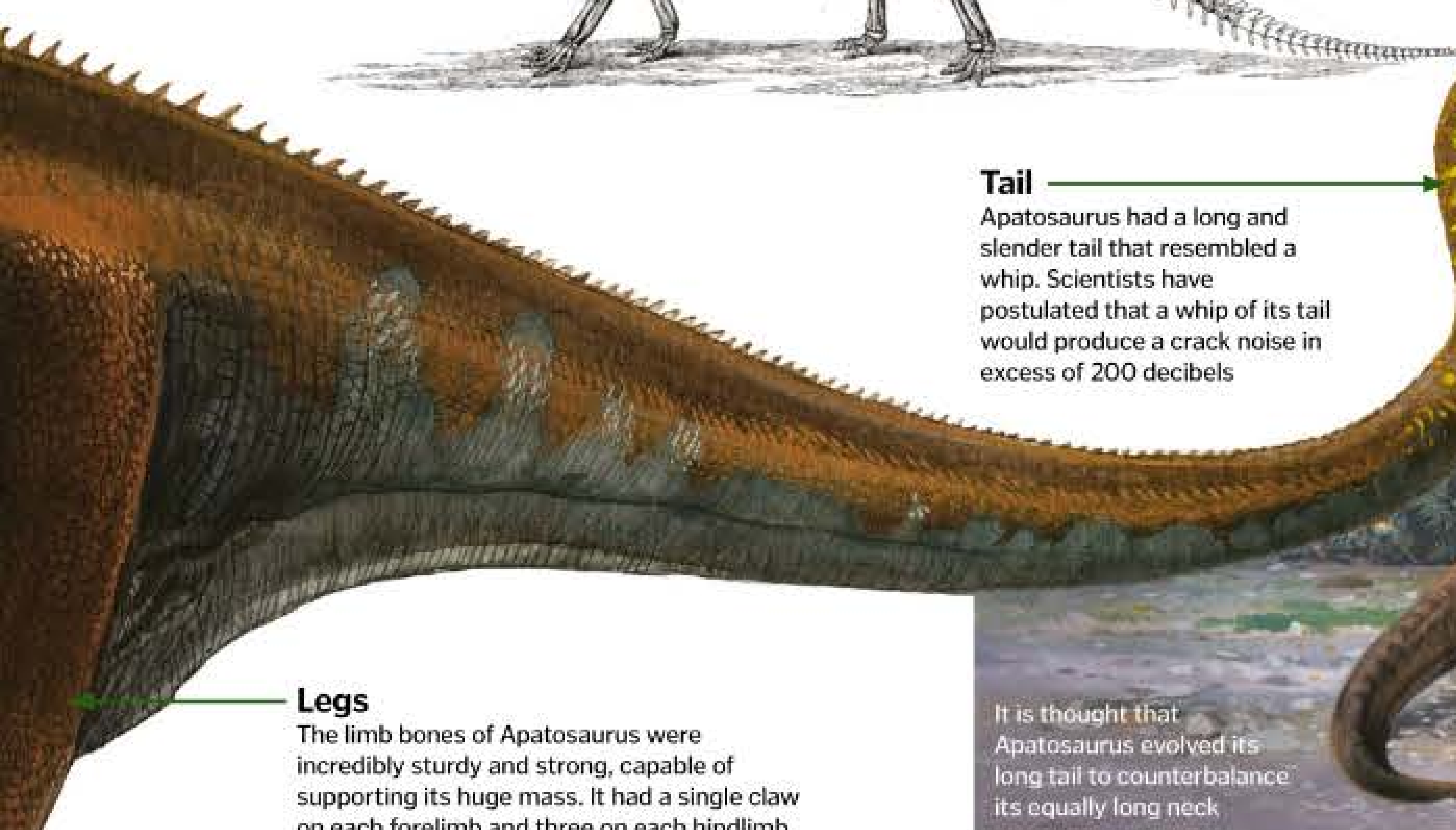
Apatosaurus vs human

How would this enormous dinosaur have sized up to a person?

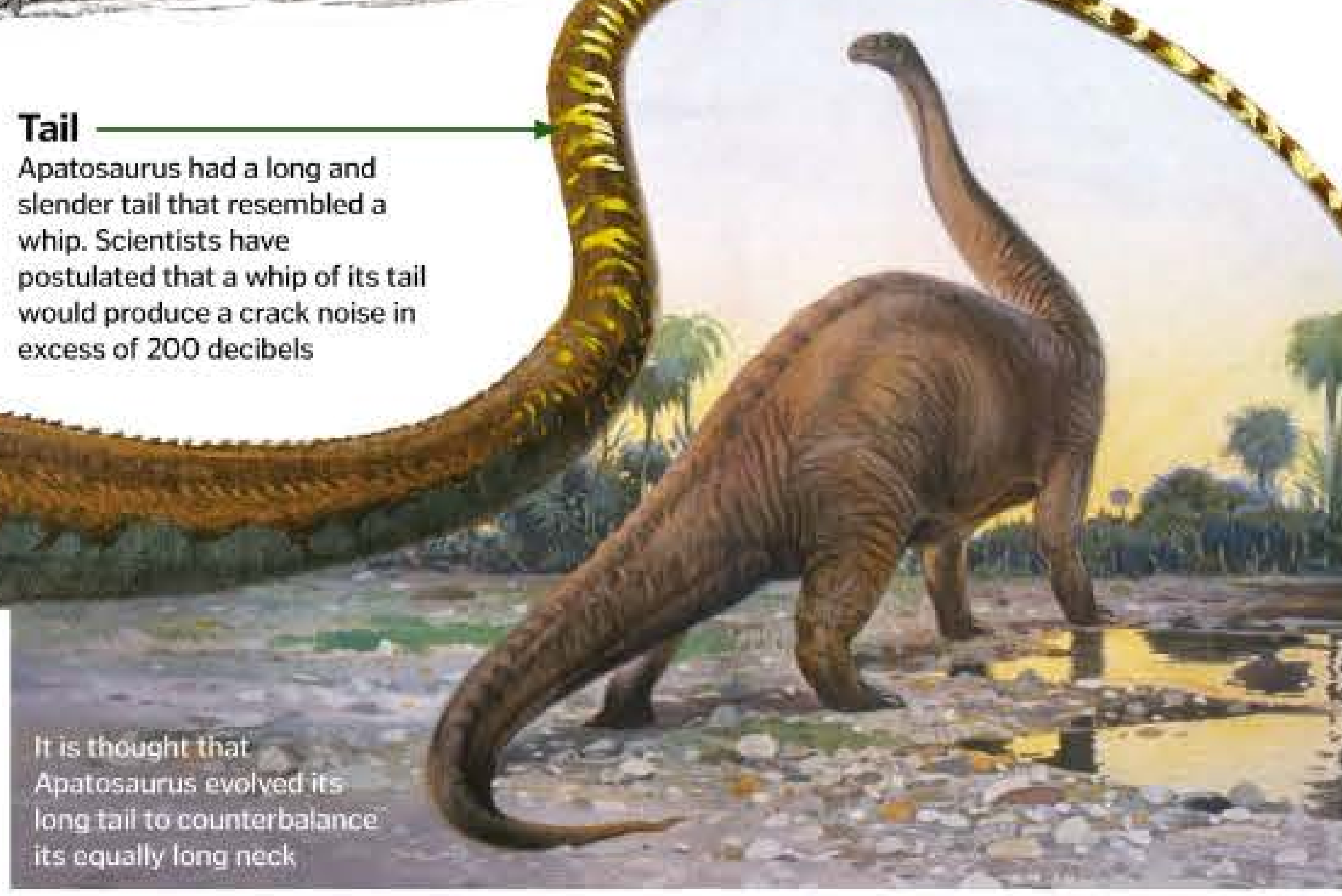




Spine
The spine of Apatosaurus was interesting in its difference to other sauropods, possessing incredibly tall spines that made up half its total height



Tail
Apatosaurus had a long and slender tail that resembled a whip. Scientists have postulated that a whip of its tail would produce a crack noise in excess of 200 decibels



It is thought that Apatosaurus evolved its long tail to counterbalance its equally long neck

Legs
The limb bones of Apatosaurus were incredibly sturdy and strong, capable of supporting its huge mass. It had a single claw on each forelimb and three on each hindlimb

The bone wars

During the beginning of the golden age of modern palaeontology, two prominent American palaeontologists, Edward Cope and Othniel Marsh, had a falling out over excavated dinosaur remains, with the men then proceeding to attempt to beat each other to unearth and describe new species of dinosaur. In this rush to become the foremost palaeontologist of the age, Marsh described first in 1877 and then later in 1879 two supposedly separate species of dinosaur. He named the first one Apatosaurus and called the second one Brontosaurus.

Following this, the name of Brontosaurus became world famous, with a complete skeleton mounted and displayed in the Peabody Museum, Yale, under the Marsh title in 1905. However, Marsh in his haste had made a terrible mistake. The Brontosaurus was actually just a fully-grown Apatosaurus and, since the Apatosaurus had been described first in 1877, its name took precedent, with 'Brontosaurus' made officially redundant in the early-20th century. Interestingly, however, as the Brontosaurus name had become firmly fixed in the public consciousness, it remained far more popular and is still in use to this day to the chagrin of many dinosaur experts.

A photograph of Othniel Marsh taken between 1865 and 1880

Stamp scandal

In 1989, the US Post Office decided to release a special edition set of four stamps depicting famous dinosaurs. These included a Tyrannosaurus, Stegosaurus, Pteranodon and, interestingly, a Brontosaurus.

The latter was included despite the fact that, as noted in 'The bone wars' boxout, the name 'Brontosaurus' had been made officially redundant in the early-20th century.

The fallout from this was massive, with many palaeontologists and dinosaur enthusiasts accusing the US Post Office of promoting 'scientific illiteracy' and re-opened a bone war-style feud between others. Indeed, even the celebrated palaeontologist Stephen Jay Gould got involved, writing a famous defence of the Brontosaurus name in his Natural History magazine piece 'Bully for Brontosaurus'.

Polar dinosaurs

Evidence shows that some dinos survived cold, dark winters

For a long time both experts and the public believed dinosaurs only thrived in tropical regions. But imagine everyone's surprise if the latest *Jurassic Park* movie had our heroes running around in thick winter coats for a change. It may seem unlikely, but our perception of dinosaurs is changing, as recent fossils have shown that dinosaurs also called much colder places home.

One such chilly habitat was the landmass now known as Australia. Nowadays this region is far from cold, but 65-100 million years ago it was considerably further south, resting right next to the continent of Antarctica.

So how did dinosaurs survive in these conditions? A previous theory suggested that they migrated to warmer climates as the coldest season descended. But this has now largely been debunked; the 'over-wintering' theory, which involves dinosaurs either enduring the cold or tucking in for winter, is now in favour.

Some of the smaller dinosaurs, in particular, are believed to have possibly burrowed into a den for winter hibernation – much like the polar bears of today. But we know that this wasn't the case for all prehistoric beasts. Analysis of polar dinosaur bones has shown that they grew all year round, which suggests that these animals did not spend months sleeping.

Fortunately for these animals, the poles weren't quite as cold as they are today, but they did experience prolonged, dark winters. This made it difficult for plants to thrive, but some hardy vegetation could provide nourishment for herbivores, which in turn was good news for the carnivores, because they had more prey to hunt.

The duck-billed giant

The fossil of a nine-metre-long herbivore unearthed in a remote part of Alaska in 2015 is the furthest north a polar dinosaur has ever been found. Paleontologists confirmed this newly discovered species after studying a set of fossilised remains, and it displays distinct differences to its relatives found further south.

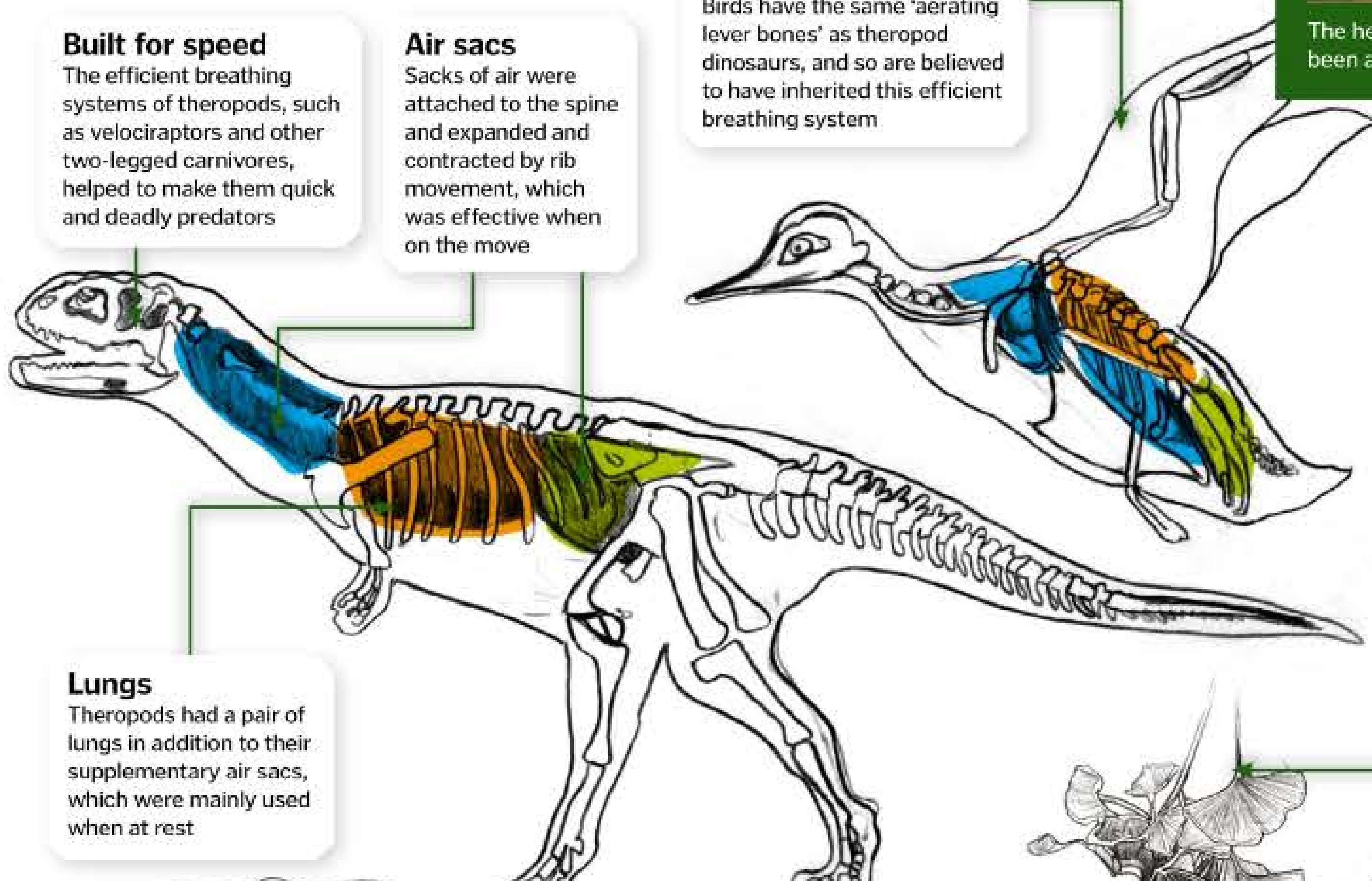
It's believed the Arctic hadrosaur stood on two of its four legs to reach food from up high. An interesting duck-billed facial structure and hundreds of teeth helped this gigantic beast to tackle the coarse forage.

As well as its ability to devour the bountiful vegetation, the hadrosaur was able to endure months of darkness and a drop in temperature over winter – and perhaps even snow. These exciting findings help to paint the picture of polar dinosaurs, solidifying their reputation as tough and adaptable animals.

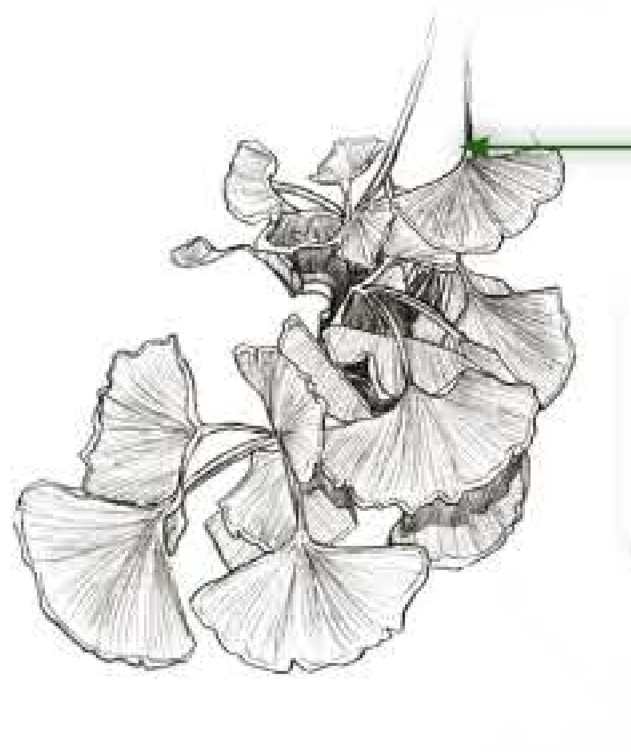
The herbivorous Arctic hadrosaur may have been a permanent resident of polar regions

Adapted for survival

A diverse selection of dinosaurs were tough enough to survive in the cold



"Fortunately for these animals, the poles weren't quite as cold as they are today"



A warmer Earth

Although polar dinosaurs were equipped for the cold, it's unknown whether they would have been able to cope in the incredibly harsh polar regions of today. Modern day climates experience temperatures so low that only the most resilient life can survive, which is quite a contrast to the land of lush vegetation that was able to grow during the Mesozoic era.

Dinosaurs were able to enjoy higher temperatures thanks to the much greater levels of carbon dioxide in the atmosphere. This warmed the planet, melted the poles, and allowed life to prosper. However, between the end of the dinosaur era and the early years of humankind, natural processes lowered the carbon dioxide levels, temperatures fell, and the poles froze once more.

Increased temperatures from high carbon dioxide levels made it easier for flora and fauna to flourish near the poles

10 deadliest dinosaurs

Counting down the fiercest, most terrifying beasts that ever lived

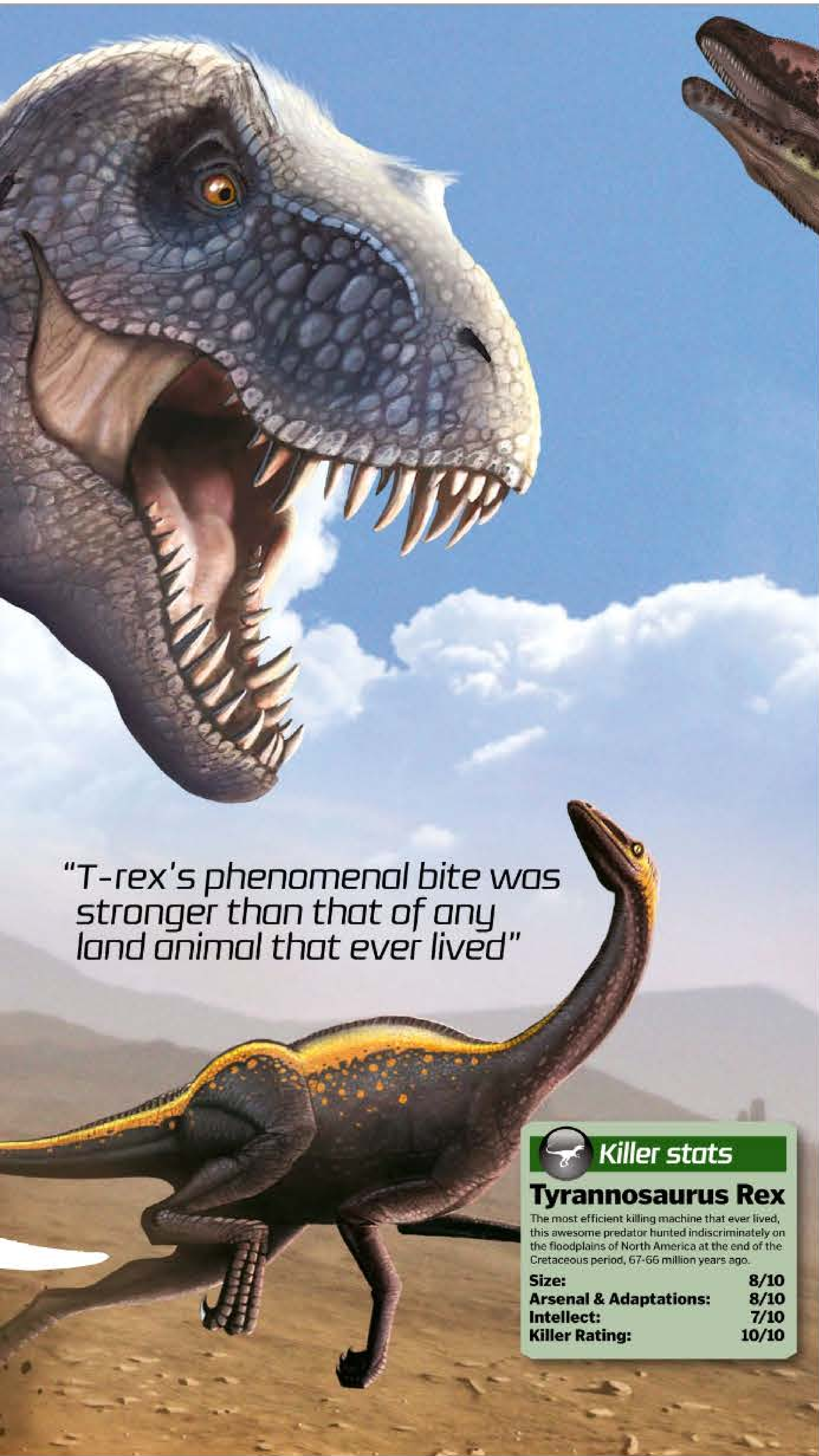
Tyrannosaurus rex

Tyrannosaurus rex ("tie-RAN-a-SORE-uss rex") needs no introduction; its reputation as the ultimate carnivore and most badass dinosaur ever to roam the Earth precedes it. Tyrannosaurus rex (T-rex for short) literally means "tyrant lizard king", and there can be no doubt that it lived up to its name.

Standing at over five metres (16.4 feet) tall and 12 metres (39.4 feet) long, and weighing a staggering seven tonnes (15,400 pounds), the T-rex was once thought to have been the largest terrestrial carnivore in history, but subsequent discoveries of fellow titans Carcharodontosaurus, Giganotosaurus and Spinosaurus challenged this.

The T-rex walked on a pair of powerful hind legs and could run as fast as a professional footballer, but balance issues meant that Giganotosaurus could outrun it. Its brain was twice the size of most other predatory giants, but its intellectual prowess wasn't a patch on that of raptors like Utahraptor. So how does T-rex manage to cling to its crown?

It may not have been the biggest, fastest, heaviest, or smartest, but the king was the ultimate all-rounder. Its extraordinary sense of smell allowed T-rex to track prey over long distances and sniff out abandoned carcasses to scavenge. And then there is its not-so-secret weapon: its phenomenal bite, which was stronger than that of any land animal that ever lived. Its bone-splintering jaws chomped down with a force almost as huge as its own body weight, bringing to bear its 60 saw-edged conical teeth. Other dinosaurs had to close their mouth around prey multiple times to bring it down; T-rex only had to bite once.



"T-rex's phenomenal bite was stronger than that of any land animal that ever lived"

Killer stats

Tyrannosaurus Rex

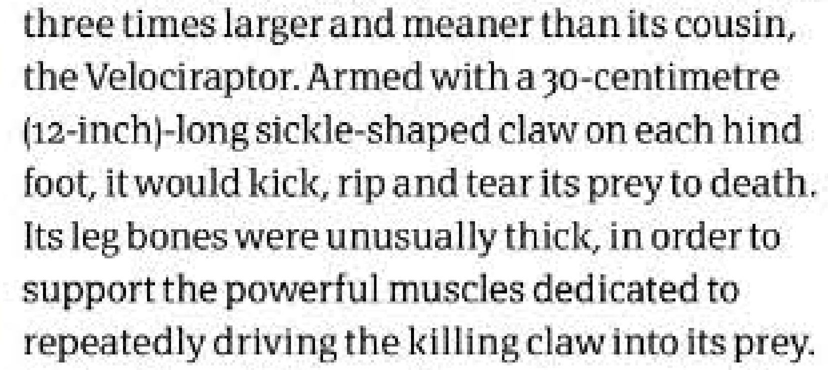
The most efficient killing machine that ever lived, this awesome predator hunted indiscriminately on the floodplains of North America at the end of the Cretaceous period, 67-66 million years ago.

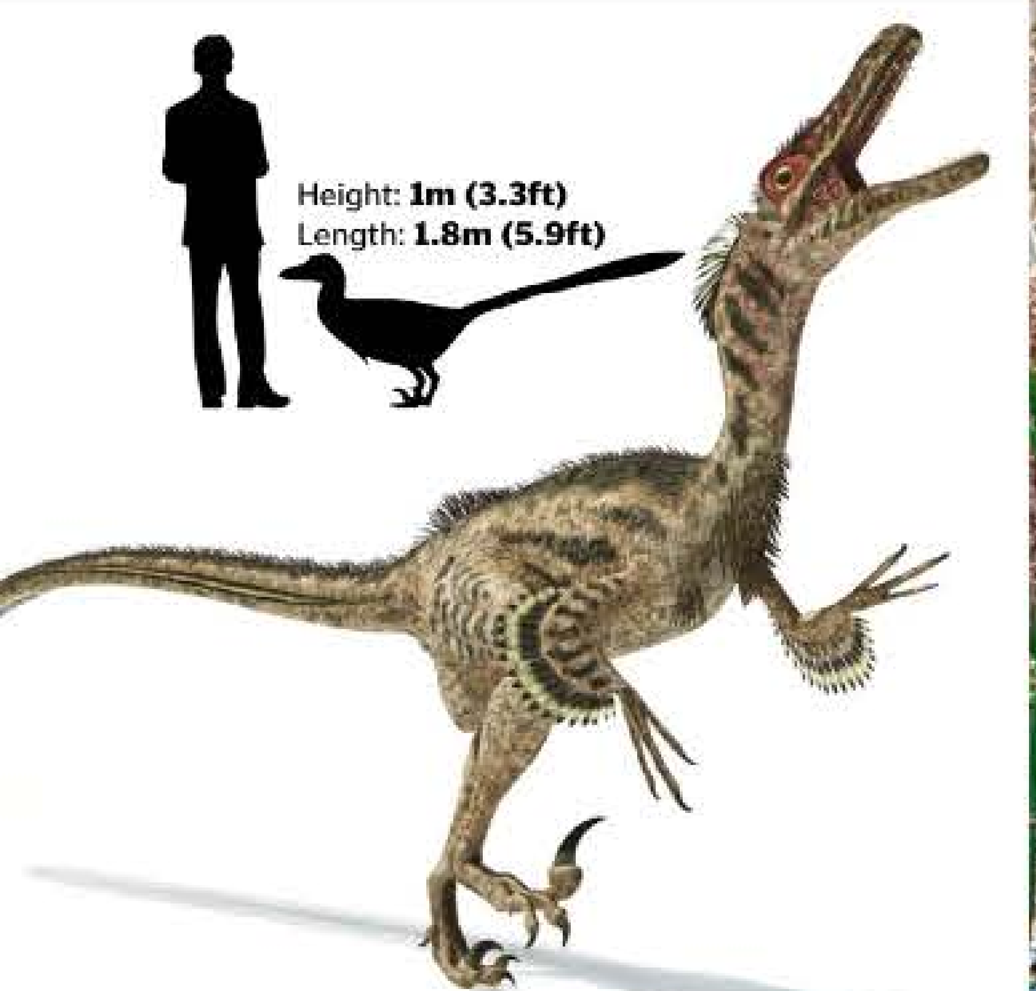
Size:	**8/10**
Arsenal & Adaptations:	**8/10**
Intellect:	**7/10**
Killer Rating:	**10/10**

Utahraptor

The mighty Utahraptor ("YOU-tah-RAP-tor") was three times larger and meaner than its cousin, the Velociraptor. Armed with a 30-centimetre (12-inch)-long sickle-shaped claw on each hind foot, it would kick, rip and tear its prey to death. Its leg bones were unusually thick, in order to support the powerful muscles dedicated to repeatedly driving the killing claw into its prey. In keeping with its smaller raptor cousins, it's possible that Utahraptor hunted in packs, like terrible three-metre (9.8-foot) -tall 500-kilogram (1,100-pound) wolves, and targeted prey many times larger than itself.

Height: **3m (9.8ft)**
Length: **6.5m (21.3ft)**





Velociraptor

Star of the infamous kitchen scene in *Jurassic Park*, the curious creature with the deadly curved toe claw has been terrorising nightmares for two decades. The film may have overstated their size and stripped them of their feathers, but it did get some things right: Velociraptors ("vel-OSS-e-RAP-tors") were fast and polished predators that oozed agility and intelligence, and may have hunted in packs.

Mapusaurus

A close cousin and look-alike of Giganotosarus, Mapusaurus ("MAH-puh-SORE-uss") hunted some of the largest dinosaurs that ever lived – the 35-metre (115-foot)-long herbivore Argentinosaurus. Its narrow blade-like teeth were ideal slicing tools, and the discovery of bones from several individuals found in one place has experts speculating that they formed groups or hunted in packs for extra lethality.

Killer stats

Troodon

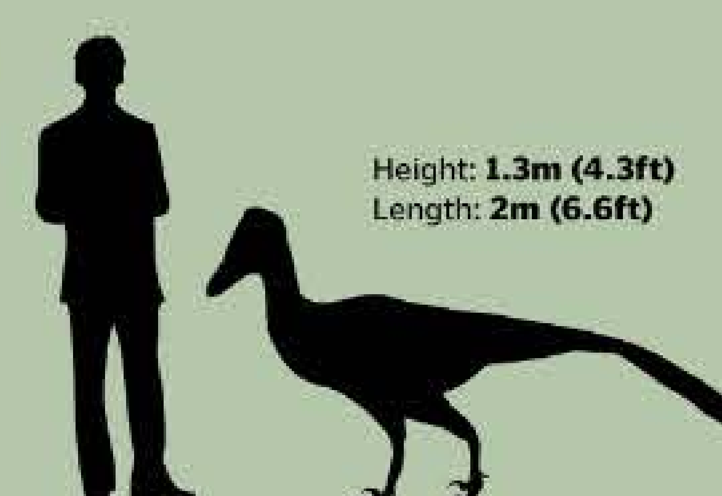
This diminutive dinosaur used cunning and cooperation to slay supposedly superior beasts in the wilds of North America during the Late Cretaceous Era, 74-65 million years ago.

Size:	**3/10**
Arsenal & Adaptations:	**8/10**
Intellect:	**10/10**
Killer Rating:	**8/10**

Troodon

Deadliness doesn't always come down to bulk and bite force. Troodon ("TROH-oh-don") – standing just 1.3 metres (4.3 feet) tall and weighing in at 40 kilograms (88 pounds) – was a wily whippet that made up for its lack of brawn with a whole lot of brain. In fact, it had the highest brain-to-body-weight ratio of any known dinosaur. Not only that; reconstructions of its brain have revealed nascent signs of folding – where more neural cells are packed into the same area for more efficient brain functioning – making it the most neurologically advanced specimen too.

The shape of fossilised skull remains suggest it possessed huge orb-like eyes that gave it superior vision – as well as the ability to see in low-lighting conditions and hunt nocturnally – and its slight frame made it extremely fleet of foot. While they may have been dwarfed by many of the behemoths on this list, a pack of alert and agile Troodons hunting as a pack could easily have brought down much bigger animals.

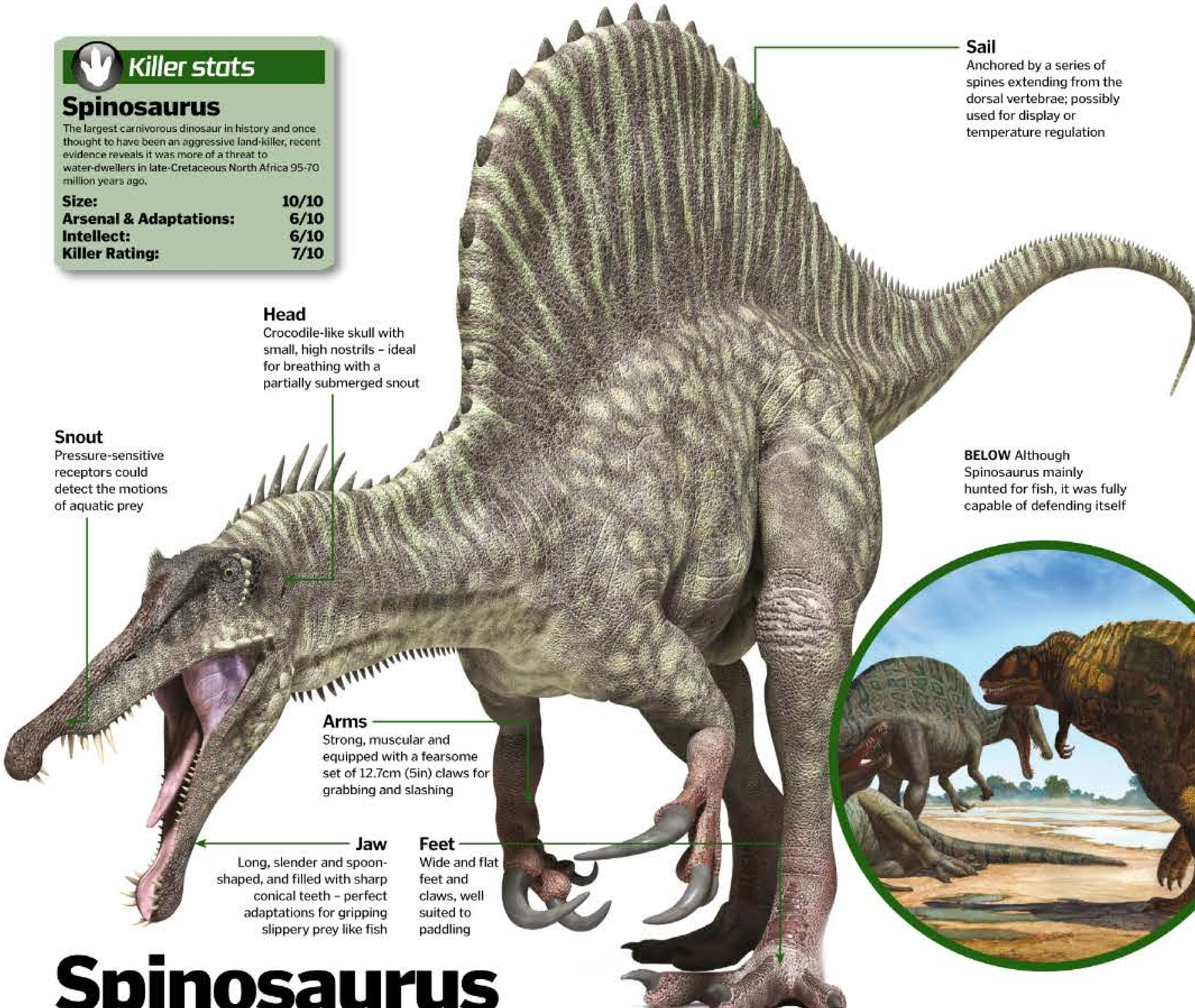


Killer stats

Spinosaurus

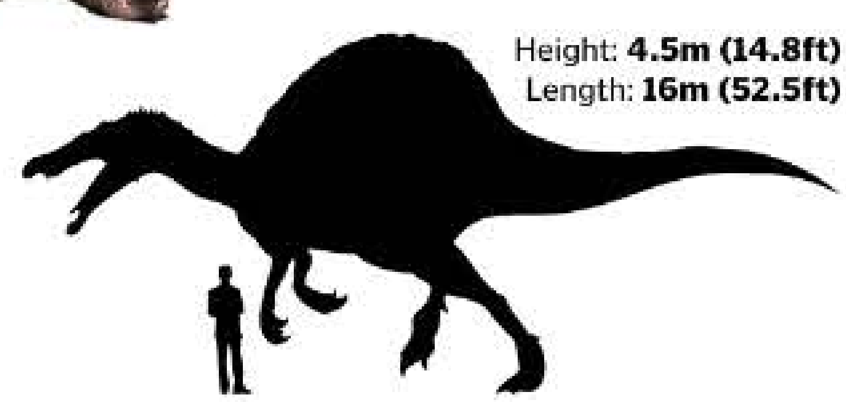
The largest carnivorous dinosaur in history and once thought to have been an aggressive land-killer, recent evidence reveals it was more of a threat to water-dwellers in late-Cretaceous North Africa 95-70 million years ago.

Size:	**10/10**
Arsenal & Adaptations:	**6/10**
Intellect:	**6/10**
Killer Rating:	**7/10**



BELOW Although Spinosaurus mainly hunted for fish, it was fully capable of defending itself

Spinosaurus



The largest carnivorous dinosaur ever to stalk the Earth, Spinosaurus is thought to have been as long as one and a half double-decker London buses – 16 metres (52.5 feet) – and as heavy as a herd of Asian elephants (20 tonnes). Its vertebrae were 20 per cent larger than those of T-rex and to top it off, it sported a gigantic sail of skin supported by two-metre (6.6-foot)-long spines protruding from its back.

Despite its imposing physique, recent evidence suggests Spinosaurus spent more of its time terrorising the water than it did the land, and would only supplement its fishy diet with scavenged carrion. Its crocodile-like jaw had smooth, conical, pointed teeth, well adapted to spearing slippery prey like Onchopristis – eight-metre (26-foot)-long prehistoric sawfish – rather than ripping flesh from bone. Special structures in its snout helped it detect pressure waves caused by prey moving in the water.

Nevertheless, Spinosaurus was fast, strong and possessed a cruel set of claws, meaning it could likely hold its own against other massive predators, like Carcharodontosaurus, who shared its territory. Despite what you might think, they never came up against the T-rex.

Killer stats

Carcharodontosaurus

Among the largest and heaviest carnivorous dinosaurs known, this hulking mouthful of razors terrorised North Africa during its reign in the mid-Cretaceous Era, 100-93 million years ago.

Size:	**8/10**
Arsenal & Adaptations:	**7/10**
Intellect:	**3/10**
Killer Rating:	**8/10**

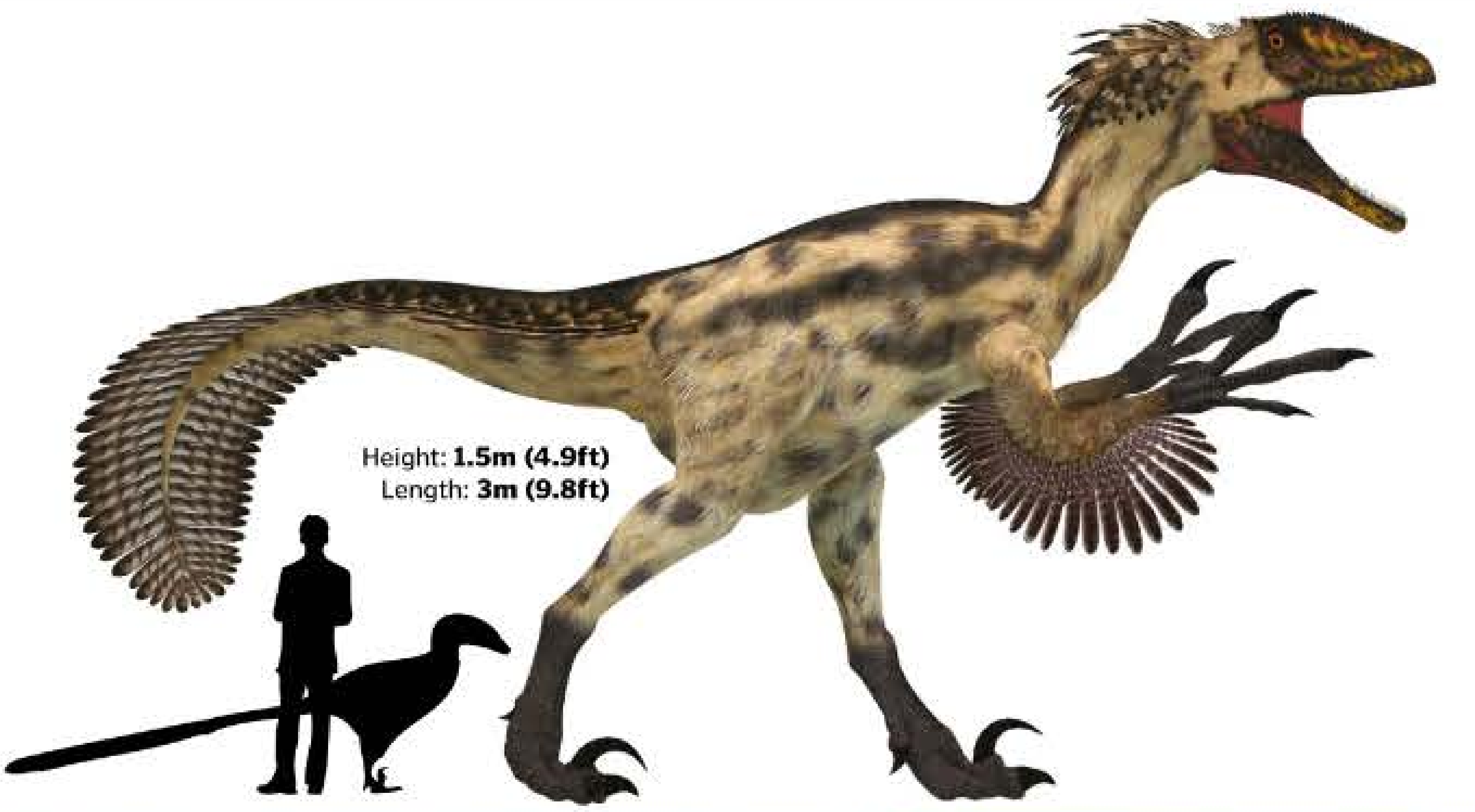
Carcharodontosaurus

Its name is a mouthful in more ways than one; Carcharodontosaurus ("Kar-KAR-o-don-toe-SORE-uss") means "shark-toothed lizard" and refers to the beast's jaw-full of 20-centimetre (eight-inch)-long serrated teeth. These could slice through flesh like switchblades through butter and leave enormous gaping wounds that would quickly incapacitate prey.

Although it was larger than T-rex and had an enormous skull the size of a person, Carcharodontosaurus – along with its close cousins Giganotosaurus and Mapusaurus – was a more primitive dinosaur with a smaller brain. Instead, it had powerful legs and fossilised tracks suggest it was capable of outrunning T-rex – at about 32 kilometres (20 miles) per hour. Whether or not it actually did – given that its disproportionately small arms would be incapable of bracing its seven-tonne weight in a fall – is another matter.

Majungasaurus

Majungasaurus ("Mah-JUNG-a-SORE-uss") has a bit of a bad-lizard reputation; telltale tooth marks on Majungasaurus bones, found on its native island of Madagascar, line up perfectly with Majungasaurus's own dental patterns. That's right – the evidence suggests this one-tonne theropod feasted on its own kin, at least occasionally – surely the hallmark of a ruthless killer? What isn't known, though, is whether these were the spoils of active hunts or just efficient tidying up of already-dead relatives.



Deinonychus

The discovery of Deinonychus ("Dee-NON-i-KUSS") in 1964 overhauled our perception of dinosaurs as languid and lumbering; here was a creature clearly built for speedy pursuit. Almost twice the size of Velociraptor (insider tip – the 'Velociraptors' in *Jurassic Park* were actually modelled after the bigger, badder Deinonychus!), but a similar weight, it was a sprightly and most likely a quick-witted pack hunter. Among other advantages, it possessed interlocking vertebrae that allowed its tail to stiffen for balance when running, and a retractable 13-centimetre (five-inch) claw on each foot to disembowel prey restrained in its hands and jaw.

Giganotosaurus

Carcharodontosaurus's South American cousin, Giganotosaurus ("GIG-a-NOTE-o-SORE-uss") was another beast to rival T-rex for size. Depending on the specimen, it is thought to have been slightly smaller than Carcharodontosaurus, but longer, taller and more slender than T-rex. It was the fastest of the three, besting the others by at least 16 kilometres (ten miles) per hour, perhaps thanks to its superior balance.

It had a very large skull but, like Carcharodontosaurus, it was more neurologically primitive than T-rex; its brain was a puny half the size of T-rex's. Still, evidence suggests it had a keen sense of smell, which coupled with its athletic prowess and eight-tonne bulk made it a formidable foe.

Like Carcharodontosaurus, Giganotosaurus's teeth were serrated and laterally compressed – wide in profile but narrow when viewed from the front – making them ideal tools to deliver a series of injurious slices to the body of its prey, which would eventually keel over from exhaustion and blood loss.

Killer stats

Giganotosaurus

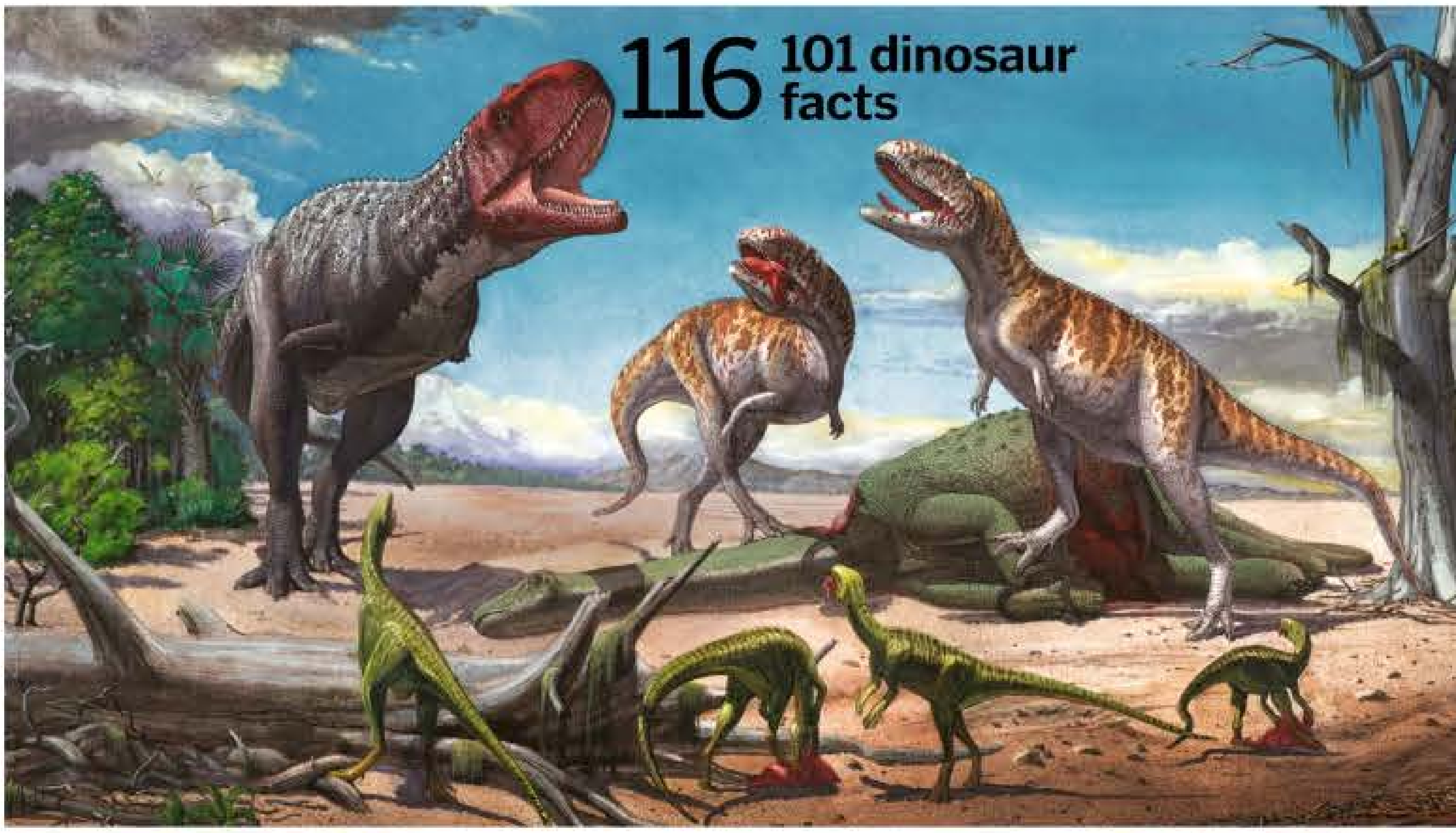
This giant razor-mouthed athlete roamed the swamplands of South America during the late-Cretaceous period, around 100-97 million years ago.

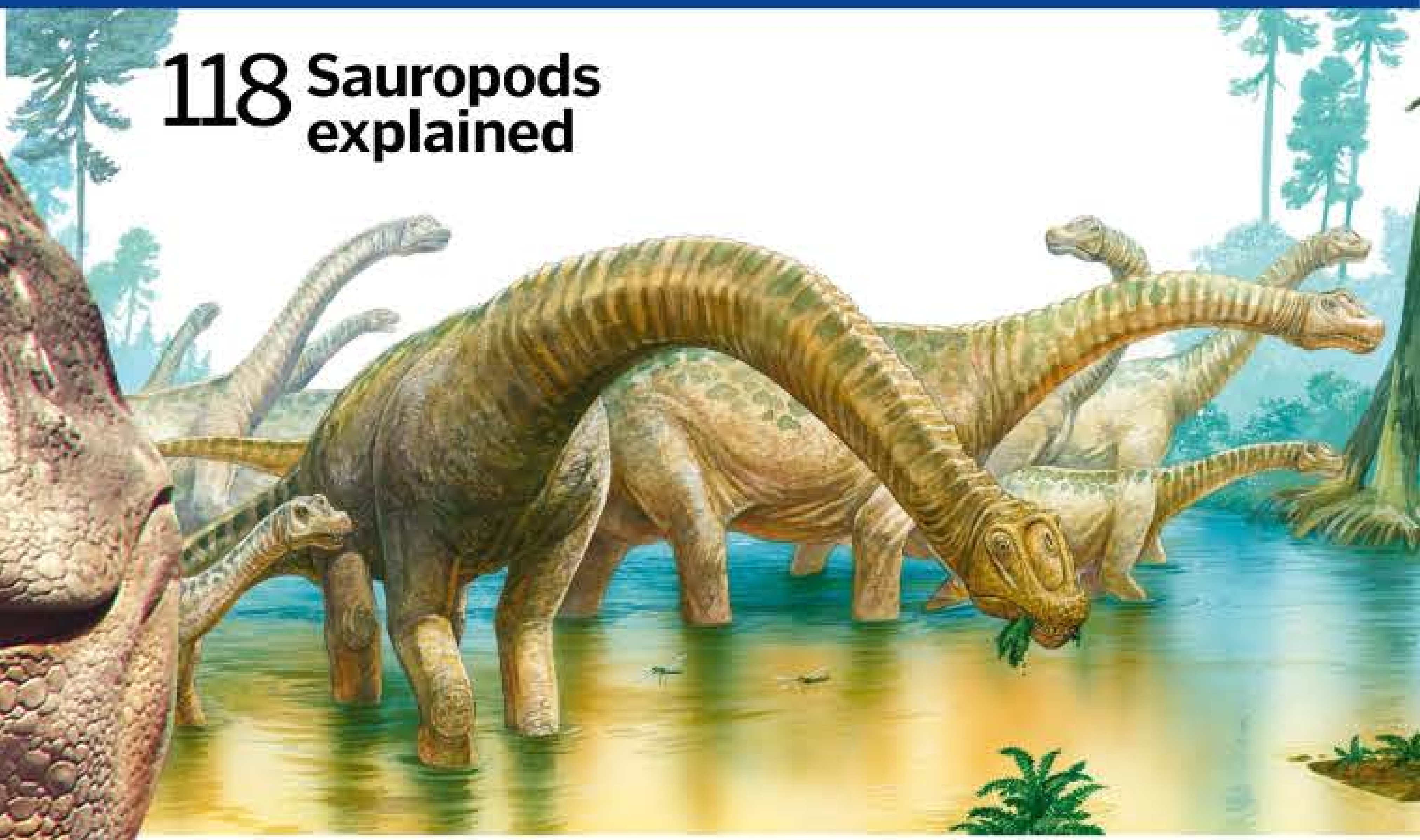
Size:	**9/10**
Arsenal & Adaptations:	**9/10**
Intellect:	**2/10**
Killer Rating:	**9/10**

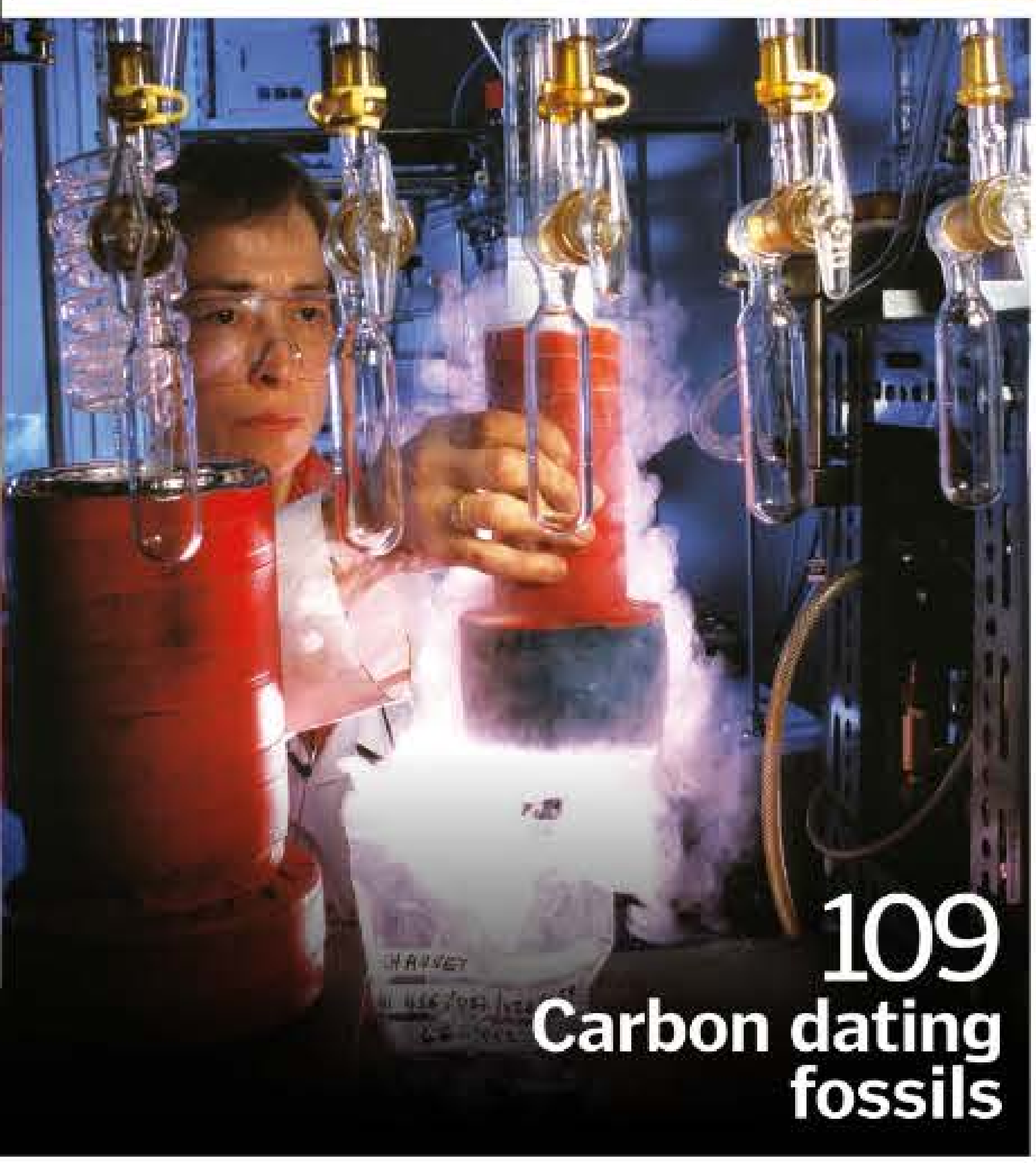
HOW IT WORKS BOOK OF DINOSAURS

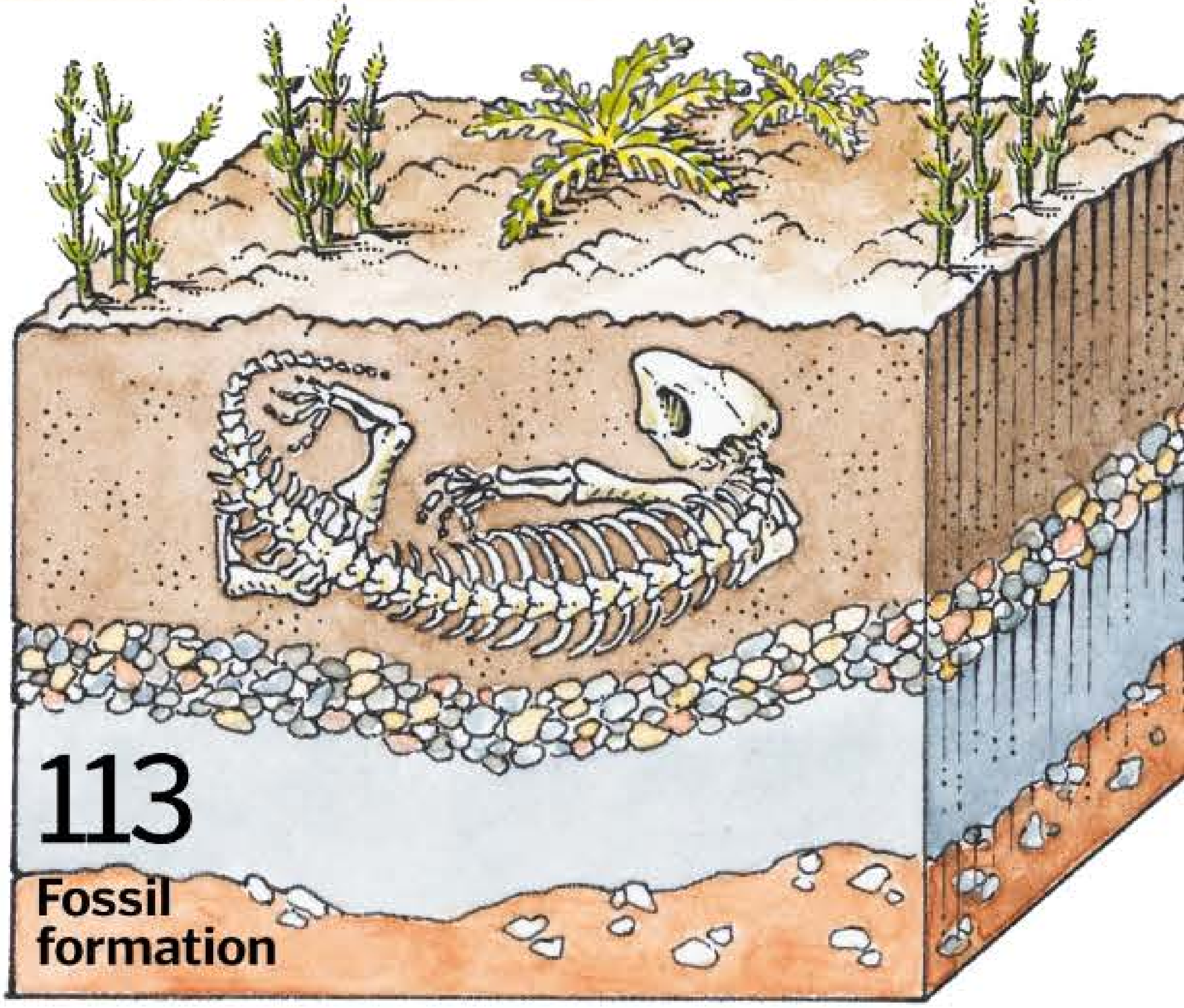
DINOSAURS' LEGACY

Dinosaurs' legacy

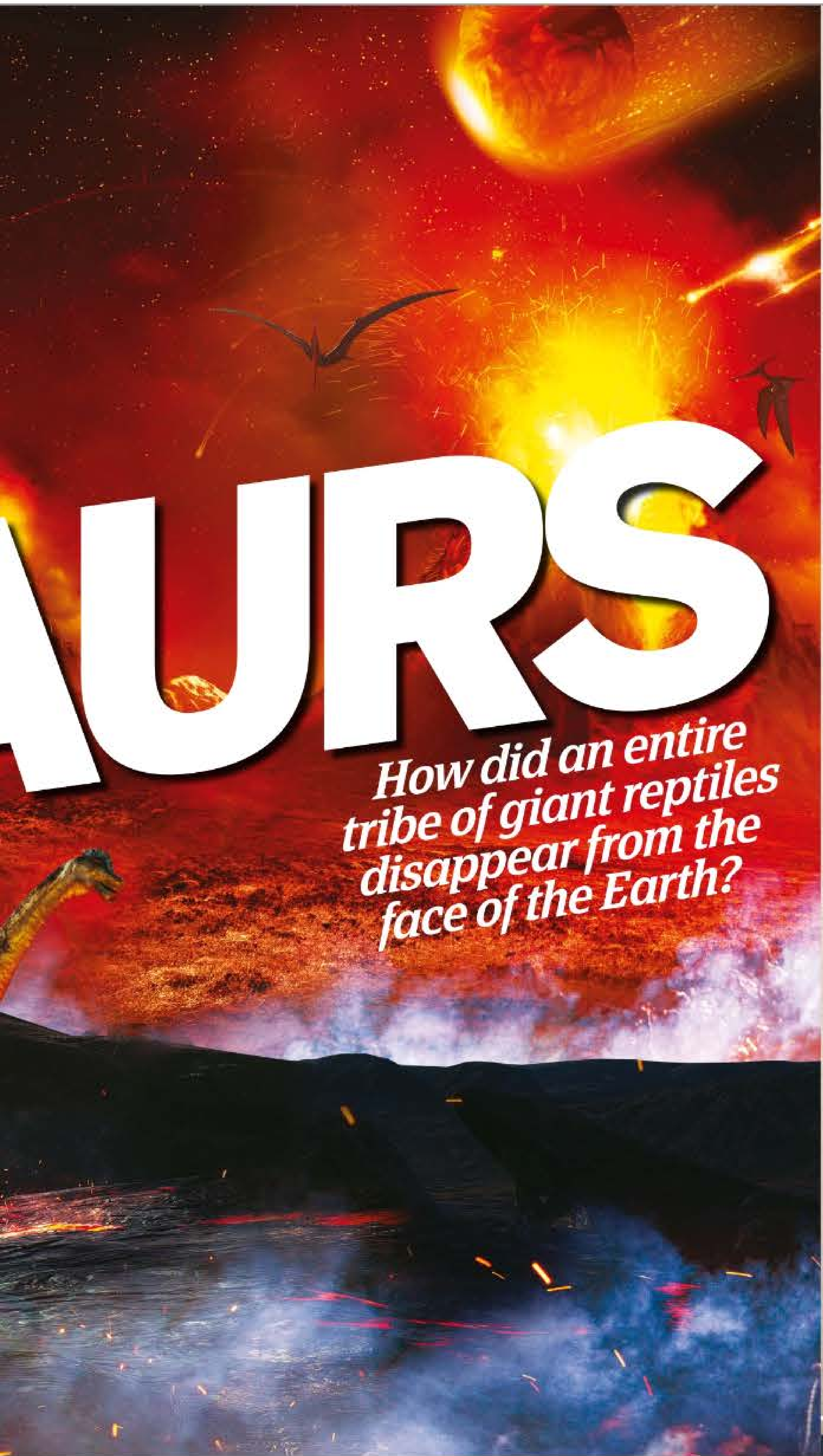








LAST DAYS OF THE DINOSA



AURS

How did an entire tribe of giant reptiles disappear from the face of the Earth?

In 1677, English naturalist Robert Plot came face-to-face with a thigh bone belonging to an animal one and a half times his height. He thought the monstrous femur belonged to a giant. Since then, enormous bones have shown up in rocks around the world, but the creatures that they belonged to are nowhere to be seen.

From the spike-thumbed iguanodons of England to the feathered microraptors of China and the iconic tyrannosaurs of the United States, dinosaurs ruled every corner of our planet, but between 66-64 million years ago they completely disappeared. The so-called KT extinction marks the transition between the Cretaceous and Tertiary periods of geological history.

During this catastrophic period, almost three-quarters of life on Earth withered away. Ammonites and belemnites disappeared from the oceans, along with dozens of species of nanoplankton, two entire groups of clams and many of the relatives of modern starfish, sea urchins, brittle stars and sea cucumbers. The ocean's top predators, the mosasaurs, also vanished. Winged pterosaurs went missing from the skies, and flowering plants died in their thousands, leaving behind a landscape dominated by ferns.

In 1980, Nobel Prize-winning American physicist, Luis Alvarez, and his son Walter noticed something unusual in the geological record. At around the time of the KT extinction, there was a band of the brittle, white transition metal, iridium. Usually rarer than gold, spikes of this unusual element appear in more than 100 places across the globe. The most likely explanation was an asteroid impact.

Iridium might be rare on our planet, but it's common in space rock. If an asteroid had collided with Earth, it could have kicked the metal into the atmosphere. As the dust settled, this would have formed a band in the rocks, marking the time of the impact.

At the level of this band there is also evidence of shocked quartz; a type of rock with distinctive microscopic features that form under intense pressure. There are also spheres of glass, made when molten rock is thrown up into the atmosphere and solidifies before it falls back to the ground. And there are vast quantities of soot, which could signal large-scale forest fires caused by burning debris from an extraterrestrial impact. Traces of the asteroid are greatest in North America. In Haiti there is a thick band of clay filled with glass spheres, and in the Gulf of Mexico tumbled rocks hint at an enormous tsunami, which could have been caused by an asteroid slamming into the planet.

To cause this level of destruction, the asteroid would have had to have been more than ten kilometres wide and travelling so fast that it

would have gouged a 100-kilometre-wide hole in the surface of the planet. It should have left an enormous crater, but the impact site was nowhere to be seen, and not everyone was convinced by the theory.

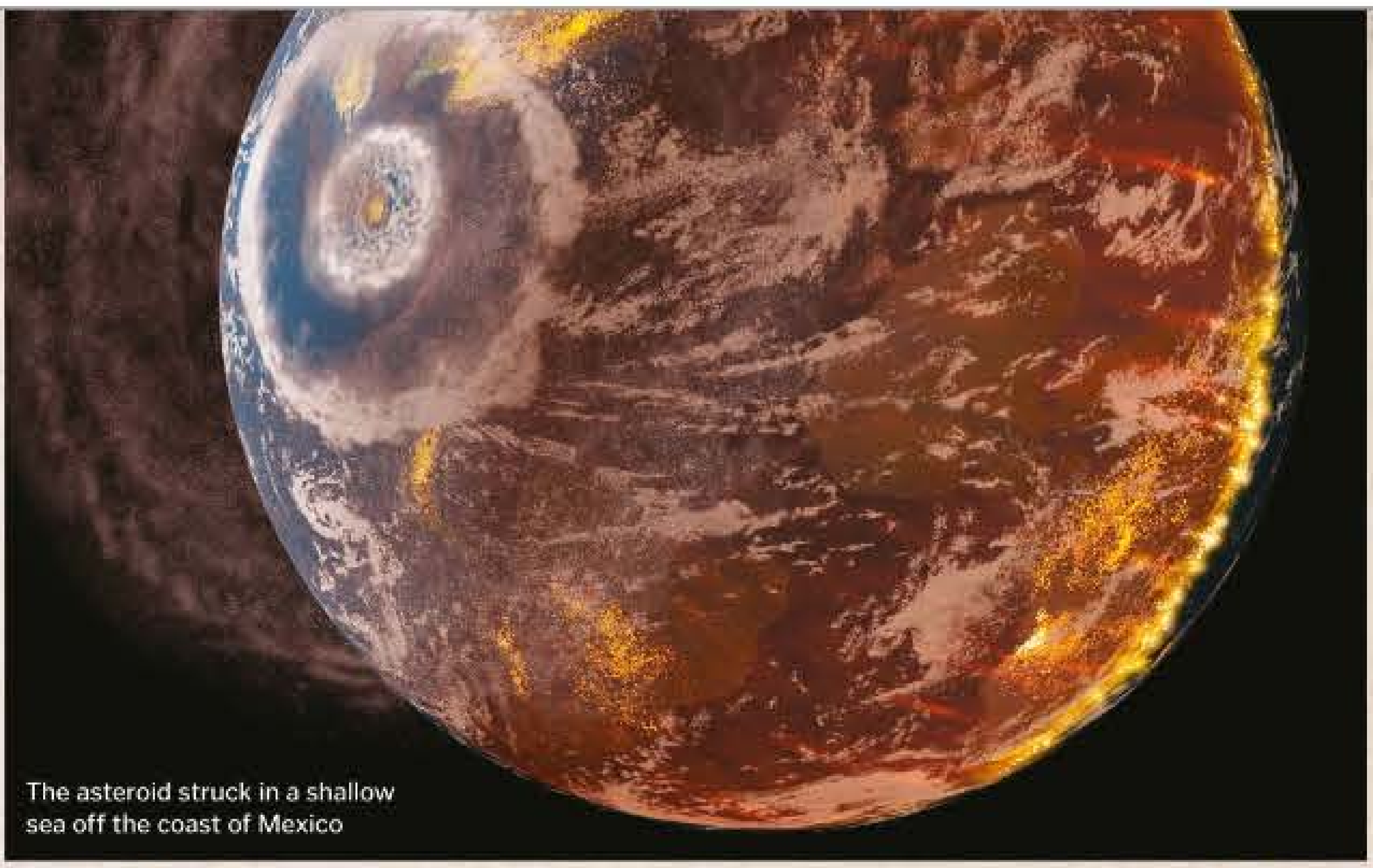
Earth was already undergoing a climate crisis; sea temperatures were rocking up and down, and water levels were rising and receding. What's more, asteroids aren't the only source of iridium, and extraterrestrial impacts aren't the only way that ash gets into the atmosphere. Even shocked quartz and glass spheres can be made by something other than an asteroid. All of these features could also be explained by volcanoes, and around the time the dinosaurs disappeared, there were some monumental eruptions.

At that time, India was an island sitting on top of a volcanic hot spot. Bubbles of hot rock were rising from the Earth's mantle, which, unlike the crust, contains high levels of iridium. The magma poured out onto the surface, depositing more than 1 million cubic metres of new rock and forming vast lava plains now known as the Deccan Traps. As this happened, ash, sulphur and metal would have billowed and plumed into the air, potentially blocking out sunlight.

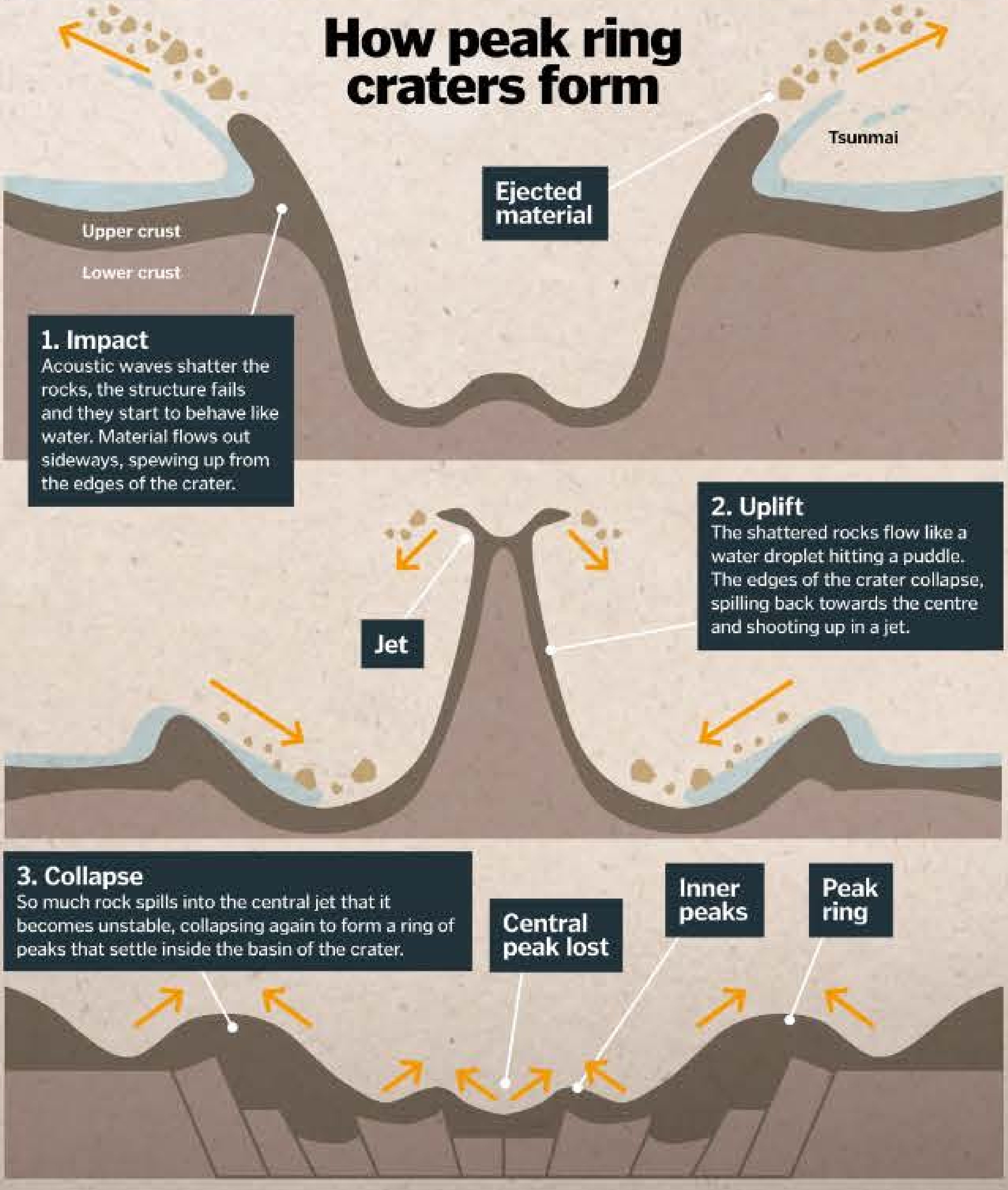
Both sides claimed the same evidence for their explanation of the trigger that caused the dinosaurs' demise, and without an actual impact crater, the Alvarez hypothesis had some gaps, but in 1990 geoscientist Alan Hildebrand found the smoking gun. Buried in a shallow sea off the coast of Mexico, there was a 180-kilometre-wide hole with strange gravity and an unusual magnetic field. It contained igneous rock, shocked quartz, spheres of glass and breccias – structures made from crushed rock glued together by mineral cement. It looked like the debris of an asteroid impact. From the shape of the crater, it appears the asteroid came in at an angle, skidding debris up towards North America. The rock would have been fractured by intense vibrations, shooting molten debris into the air, and the thermal shock would have been so intense that everything within sight of the impact would have been totally obliterated.

What followed would have been an earthquake of a magnitude unmatched by even the most powerful in recorded history. Vast tsunami waves would have been hurled across the oceans and debris from the impact site would have shot up with such force that some escaped the atmosphere. As the jettisoned rocks returned they would have burnt up, raining fire across the ground. Plants and animals in the surrounding area would have died instantly or within a matter of days.

Later, as fragments of ash, sulphur and soot from burning forests clogged the air, the world would


The asteroid struck in a shallow sea off the coast of Mexico

How peak ring craters form



An extinction in numbers

10km
THE SIZE OF THE ASTEROID

180km
THE WIDTH OF THE CHICXULUB CRATER

65-66 million
THE NUMBER OF YEARS THAT HAVE PASSED SINCE THE IMPACT

11
THE MAGNITUDE OF THE EARTHQUAKE THAT WOULD HAVE SHAKEN EARTH AFTER THE IMPACT

BIGGEST RECORDED QUAKES COMPARED

9.5 VALDIVIA, CHILE, 1990
9.2 PRINCE WILLIAM SOUND, ALASKA, 1964
9.1 SUMATRA, INDONESIA, 2004
9.1 SENDAI, JAPAN, 2011
9.0 KAMCHATKA, RUSSIA, 1952

70%
THE ESTIMATED PROPORTION OF SPECIES WIPED OUT BY THE IMPACT

10 degrees
THE RISE IN GLOBAL TEMPERATURE FOLLOWING THE IMPACT

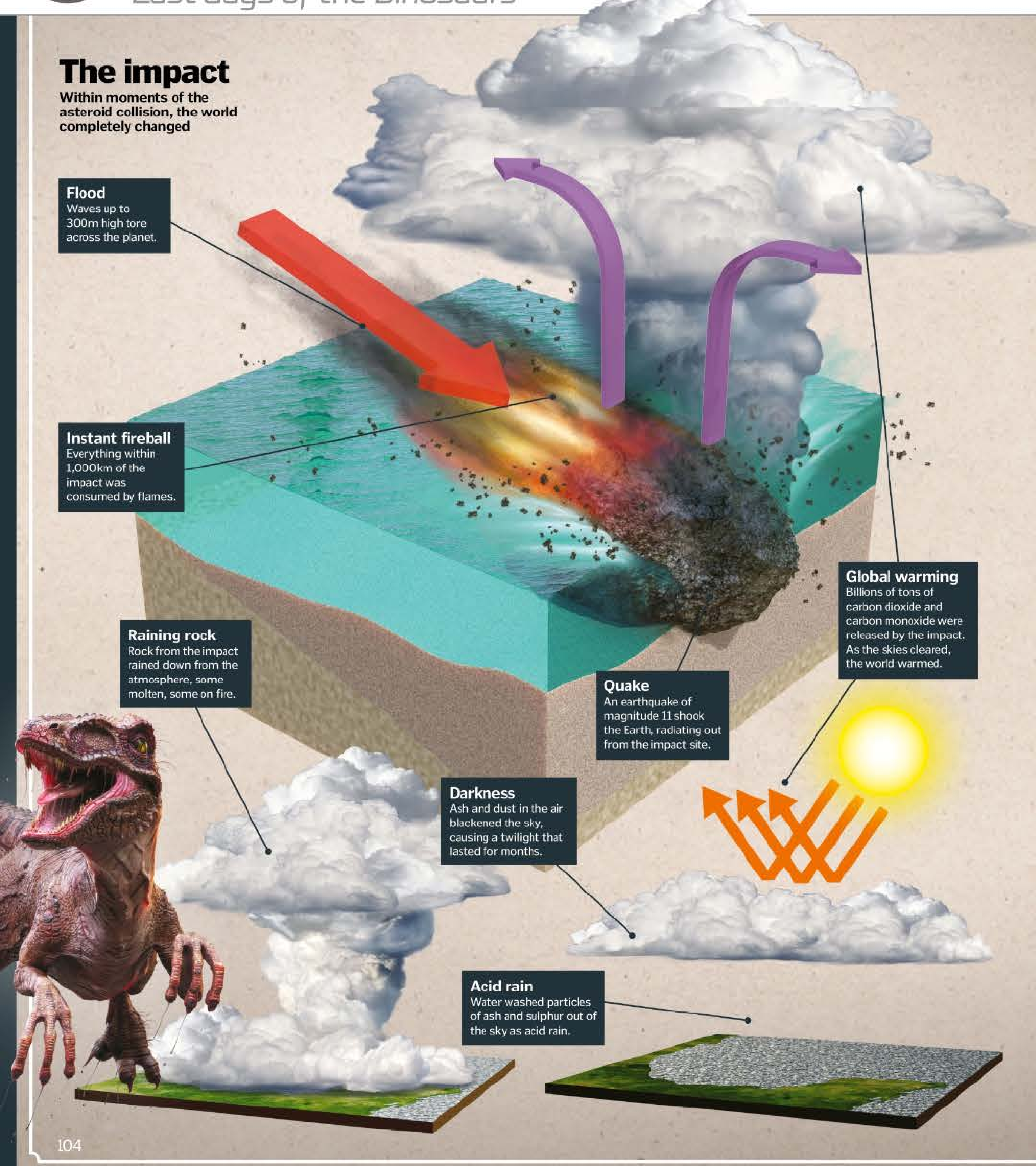
100 million megatons
THE BLAST FORCE OF THE IMPACT

The asteroid came down in a shallow sea, triggering a massive tidal wave

Glass and rock rained from the sky over North America

The impact

Within moments of the asteroid collision, the world completely changed



DID YOU KNOW? *Along with the likes of crocodiles and sharks, the platypus also survived the KT extinction*

have been plunged into perpetual twilight for weeks or even months. This 'impact winter' would have hit photosynthesisers hard, knocking out plankton in the seas and plants on land. With the bottom falling out of the food chain, entire ecosystems would have started to feel the strain.

The dust poured out of the sky as acid rain, but unfortunately the ordeal was not yet over. The Chicxulub crater, as it is now known, sits right in the middle of a three-kilometre-thick layer of carbonate rock. It acts as solid storage for greenhouse gases like carbon dioxide, and when struck, it could have sent temperatures spiralling. As the air finally cleared, billions of tons of these greenhouse gases would have triggered rampant global warming.

As Hildebrand said at the time of the discovery: "The Chicxulub impact, having presumably produced the largest impact crater on Earth, would have caused a mass extinction."

But even with the crater identified, some people still have their doubts. The most complete fossil record comes from North America, but even so, it's hard to create an exact timeline. Rock that old can't be carbon-dated, so it's not easy to tell if the dinosaurs all died at once, or if the extinction happened gradually. And not all species were preserved, so it's hard to piece together the ecosystem in enough detail to understand what caused it to fall apart. Specific conditions are needed to preserve the bones of fallen animals, and many perished without a trace.

Although there is good evidence that an asteroid did strike at Chicxulub, whether it killed the dinosaurs is hard to confirm. Some scientists argue that the impact happened about 300,000 years before the mass extinction, because some of the fossil evidence sits in layers of sediment above the impact line.

It's possible that this chunk of sediment was thrown on top of the rocks by tsunamis triggered by the asteroid, but it's also possible that the sediment

Incineration
Everything in the surrounding area was charred by an enormous fireball.

Darkness falls
The debris blocked out sunlight, plunging the Earth into a lengthy period of darkness.

Resurgence
As the dust cleared, surviving seeds and spores started to grow and animals emerged.

"With smoke from burning forests filling the air, the world was plunged into twilight"

What a difference a moment makes

The Chicxulub crater sits just off the coast of Mexico, in a shallow sea where the sediment was once filled with carbon and sulphur. When the asteroid struck, this rock shot into the atmosphere. 100 billion tons of sulphate particles and carbon – in the form of carbon dioxide, carbon monoxide and methane – entered the air. The sulphate first reflected the light, cooling the planet, but when it washed out of the sky as acid rain the carbon turned the atmosphere into a greenhouse and global temperatures climbed by degrees.

But a BBC documentary recently revealed that if the impact had come just seconds later, the rock would likely have settled in the depths of the ocean. Tsunami waves would still have flooded the surface, but the killer sulphur and greenhouse gases might never have entered the atmosphere and the dinosaurs may have been spared.

If the asteroid had come down in the deep ocean, the dinosaurs might have survived

was laid down gradually and that the extinction of the dinosaurs wasn't as rapid as it might first appear. There's evidence that animals burrowed into the soft rock and there's erosion that looks like it was created by flowing water.

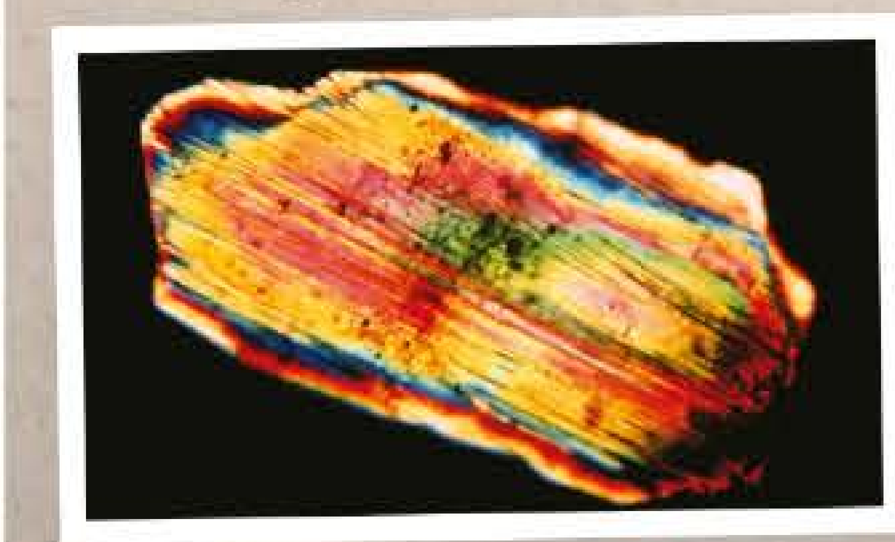
To dig deeper into the role of Chicxulub in the last days of the dinosaurs, scientists have been drilling into the remains of the impact site. Chicxulub is the largest impact crater on Earth. The asteroid that caused this hole was so big that it created a distinctive ring of molten and fragmented rock inside the outline of the crater – the so-called 'peak ring'. Since the impact the crater has been buried in 17 metres of water and 500 metres of limestone.

Between 2001 and 2002, the International Continental Drilling Program piled into the structure from the land in Mexico, revealing rock known as 'impact melt' that was likely made from fragments of rock that were shattered, spewed and then glued together when the crater formed. The drills also revealed evidence of hydrothermal activity caused by the huge impact, hinting that steam might have vented onto the crater for more than a million years after the asteroid struck.

In 2016, using a diamond-tipped drill, scientists bored into the structure again, this time targeting the peak ring to find out how it was formed and what happened in the aftermath. One startling discovery was the presence of pink granite in their drill samples. This crustal rock should have been down at a depth of 7,600 metres, but it turned up at 760 metres, evidence of the intense shock that crumpled and shook the Earth below.

There are still many unanswered questions about the extinction of the dinosaurs, and the reality is that we won't ever know the truth of what happened for sure. The Chicxulub crater is thought to have spawned one of the most devastating extinction events of all time, but evidence being gathered from the remains of the crater hint that impacts can nurture life as well as destroy it.

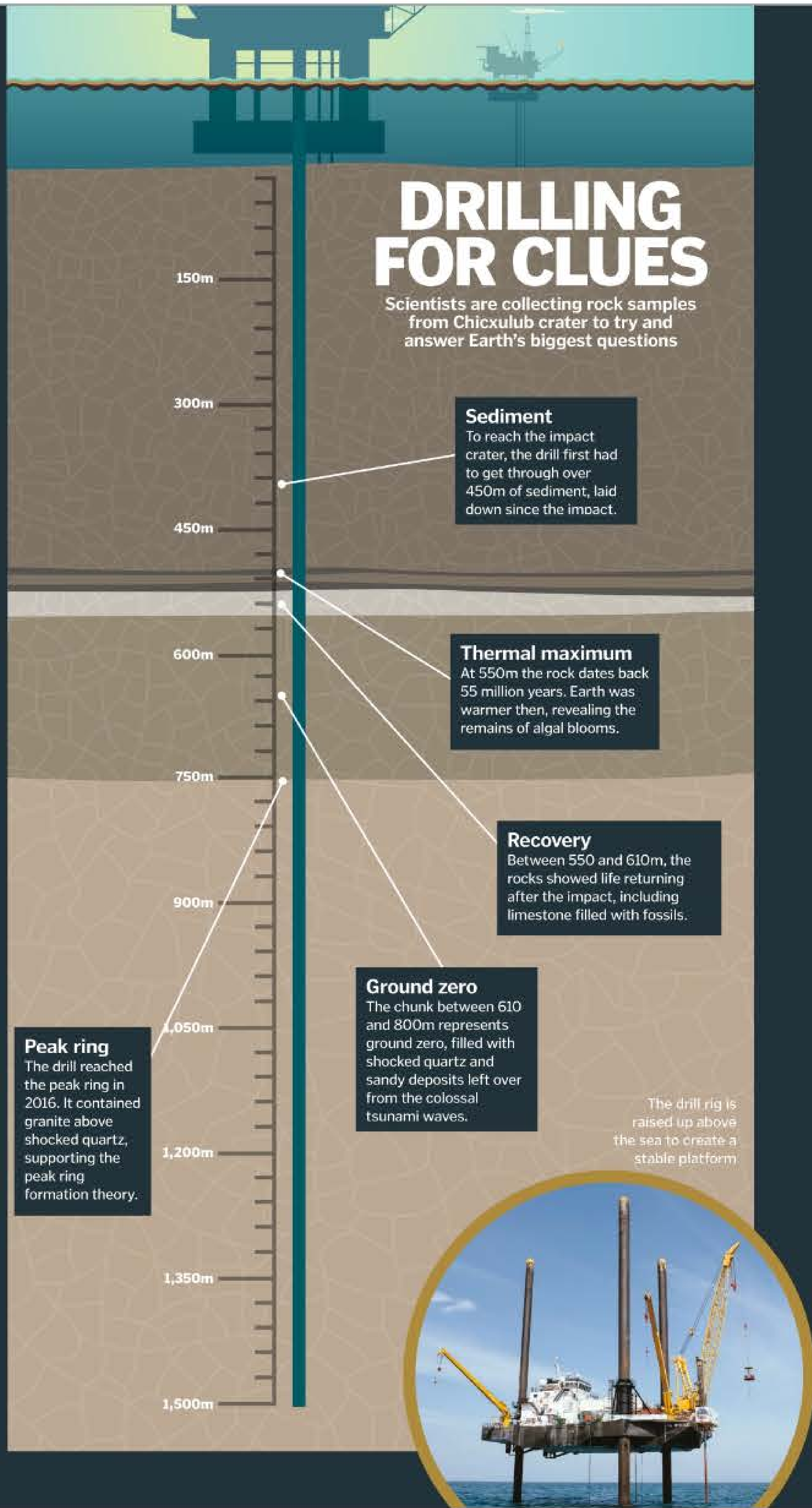
Not only did the KT extinction make way for the rise of mammals; the most recent drilling expedition revealed a large network of channels that were filled



The stress lines inside shocked quartz are caused by intense pressure

DRILLING FOR CLUES

Scientists are collecting rock samples from Chicxulub crater to try and answer Earth's biggest questions



Sediment
To reach the impact crater, the drill first had to get through over 450m of sediment, laid down since the impact.

Thermal maximum
At 550m the rock dates back 55 million years. Earth was warmer then, revealing the remains of algal blooms.

Recovery
Between 550 and 610m, the rocks showed life returning after the impact, including limestone filled with fossils.

Ground zero
The chunk between 610 and 800m represents ground zero, filled with shocked quartz and sandy deposits left over from the colossal tsunami waves.

Peak ring
The drill reached the peak ring in 2016. It contained granite above shocked quartz, supporting the peak ring formation theory.

The drill rig is raised up above the sea to create a stable platform

with warm water after the impact. At first they would have been too hot for even the hardiest of life forms, but as they cooled, microscopic life could have thrived in the warm, damp cracks, nourished by minerals leaching out of the rocks. And this has exciting implications for the origins of all living things.

Though life was already firmly established by the time the Chicxulub asteroid arrived, the crater gives us a glimpse into the kinds of conditions that might have been present on the ancient, lifeless Earth. Charles Darwin thought that life might have begun in a "warm little pond", where minerals mixed with water and organic molecules. Asteroids are stuffed with organic compounds that could have provided the ingredients for the chemistry life to begin, and if they set up warm, wet, mineral-rich niches when they strike the Earth, they could be the parents of Darwin's little ponds.

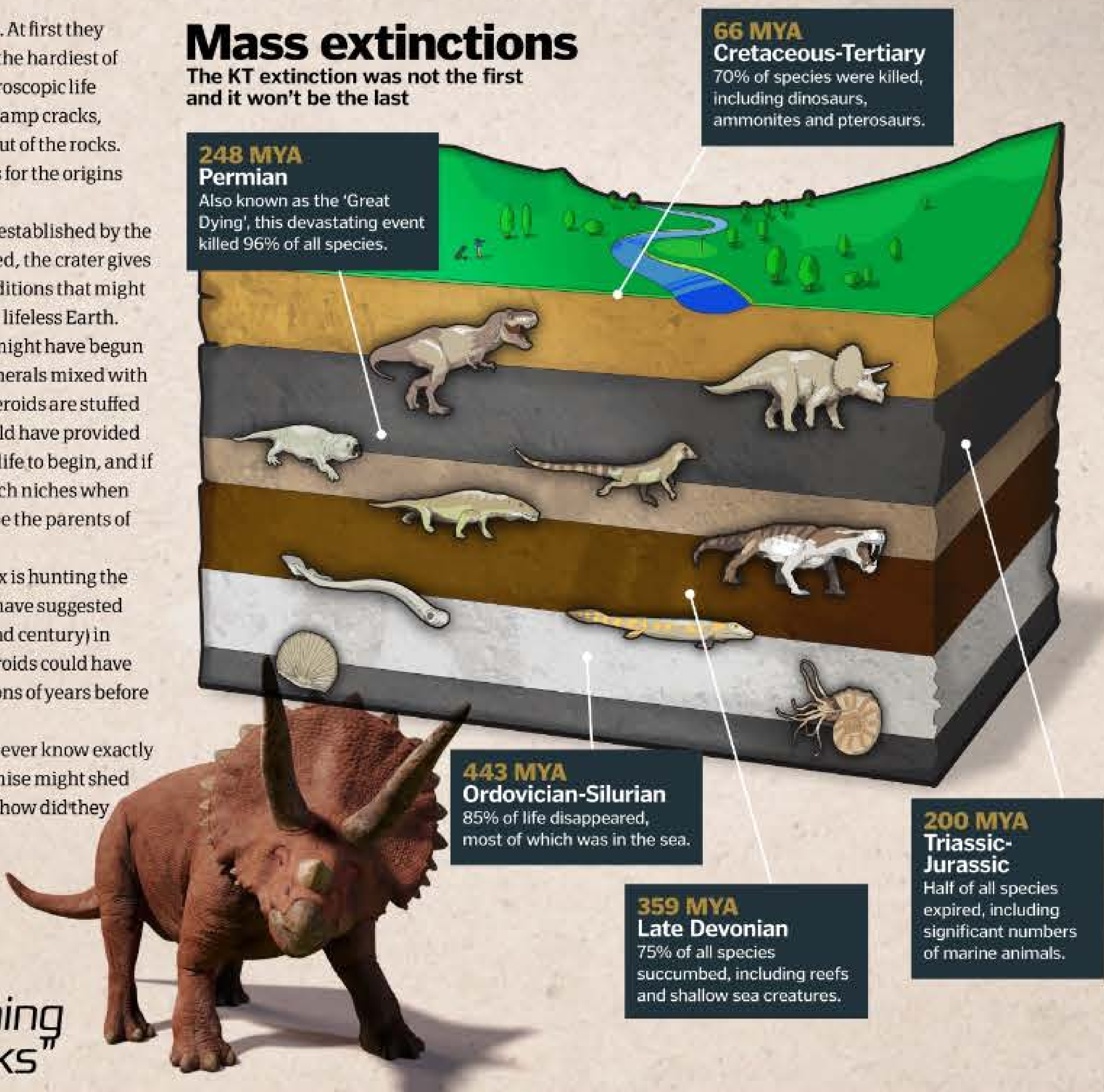
As we speak, NASA's OSIRIS-REx is hunting the asteroid Bennu (which scientists have suggested could collide with Earth in the 22nd century) in search of clues as to whether asteroids could have helped life to begin on Earth billions of years before the dinosaurs even existed.

While it is unlikely that we will ever know exactly how the dinosaurs died, their demise might shed light on an even bigger question – how did they get here in the first place?

> "Microbes may have thrived, nourished by minerals leaching out of the rocks"

Mass extinctions

The KT extinction was not the first and it won't be the last



Making way for mammals

The KT extinction event devastated the Earth, but without it, we wouldn't be here today. As the dominant land animals struggled to survive in a world charred by debris, blackened by sulphur and soot and heated by greenhouse gases, tiny mammals were shielded in their burrows. Many birds, reptiles and amphibians were also spared; saved by their small body size and flexible, often insect-based, diets. Some freshwater species also fared well; their food chain includes detritus – nutrients released by decomposition – which washes into streams and lakes, providing a steady supply of fuel.

As Earth started to recover there were gaps in the food chain for these animals to fill and the survivors spread out to take the places of the dinosaurs. Over time they evolved to become the huge variety of species that we see today.

Small animals including mammals survived the KT extinction

What are fossils?

Obliterating the traditional ideas about the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet

Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways

Adpression
A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way

Resin
Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form

Bioimmuration
Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters

Permineralisation
A process in which mineral deposits form internal casts of organisms, permineralisation works when a deceased animal dies and then is rapidly submerged with groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast

Recrystallisation
When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised

Mold
A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals

Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.

This scientist is dating archaeological specimens in a Tandetron particle accelerator

The origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in a effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with 12-inch fangs and massive creatures twice the size of a double-decker bus have long since ceased to exist. They are forgotten, buried by not just millions, but billions of years. Still, all is not lost to us. By exploiting Earth's natural processes and modern technology over the last two hundred years, scientists and palaeontologists have begun to unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' boxout) but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to

> *"The softer parts of fossilised creatures tend not to survive due to the rapidity of decay"*

be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite (an extinct marine arthropod) are only found in certain rock strata (layers of sedimentary and igneous rocks formed through mineral deposition over millions of years), which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil and/or the period.

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relatedness between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as archaeopteryx – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock (commonly referred to as the 'overburden') is removed using large tools up to a distance of two to three inches from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.

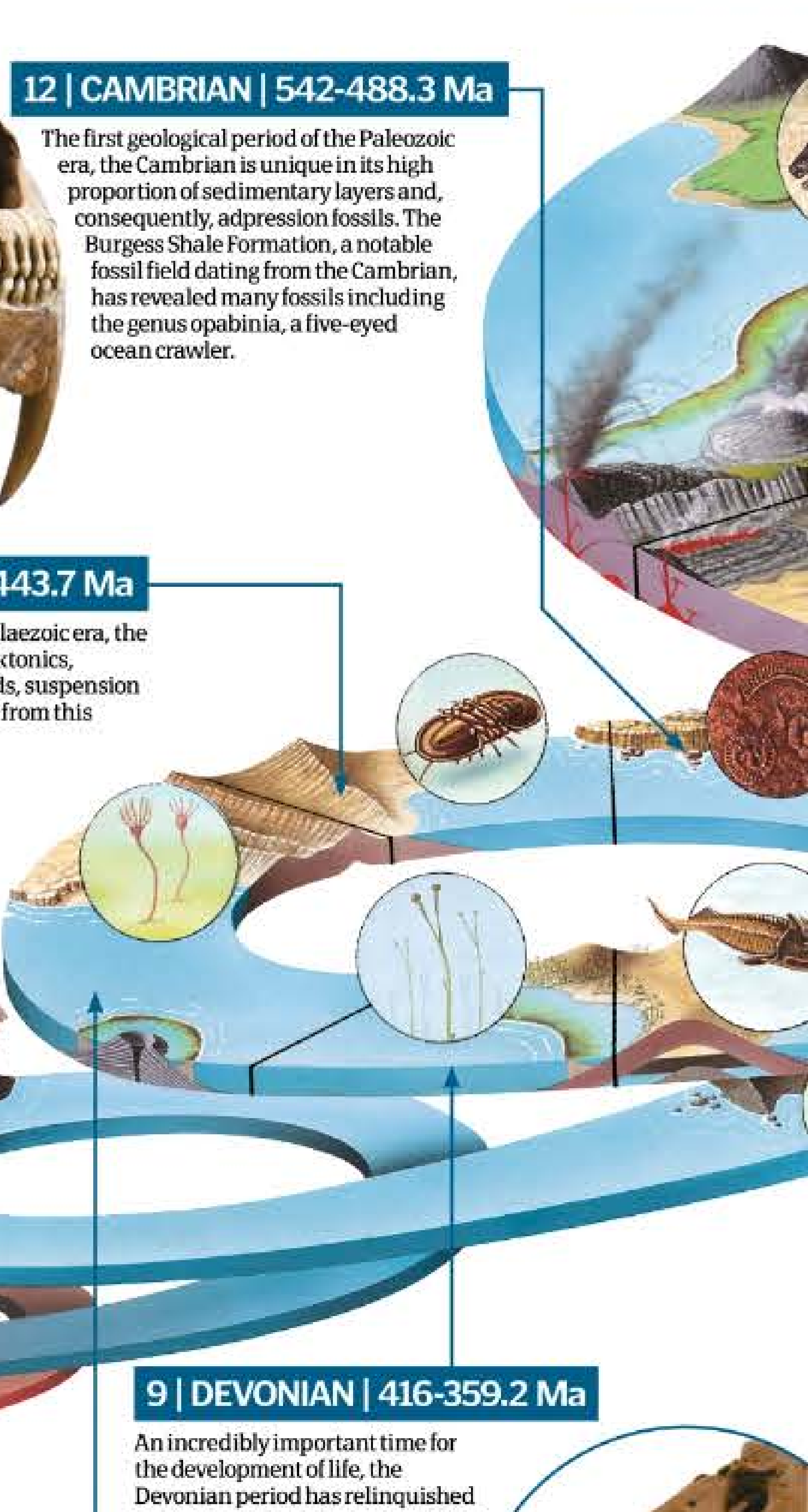
A Europasaurus fossil is examined

© Nils Knötschke

The fossil record

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale

© Wallace63



12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus opabinia, a five-eyed ocean crawler.

11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels on the Palaezoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.

© jlorenzi

10 | SILURIAN | 443.7-416 Ma

With its base set at major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.

9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthopods, become entrenched and seed-bearing plants spread across dry lands. A notable Devonian find is the genus tiktaalik.

DID YOU KNOW? The minimum age for an excavated specimen to be classed as a fossil is 10,000 years


© DanielCD

3 | PALEOGENE | 65.5-23.03 Ma

The first period of the Cenozoic era, the Paleogene is notable for the rise of mammals as the dominant animal group on Earth, driven by the Cretaceous-Tertiary extinction event that wiped out the dinosaurs. The most important fossil to be discovered from this period is Darwinius, a lemur-like creature uncovered from a shale quarry in Messel, Germany.

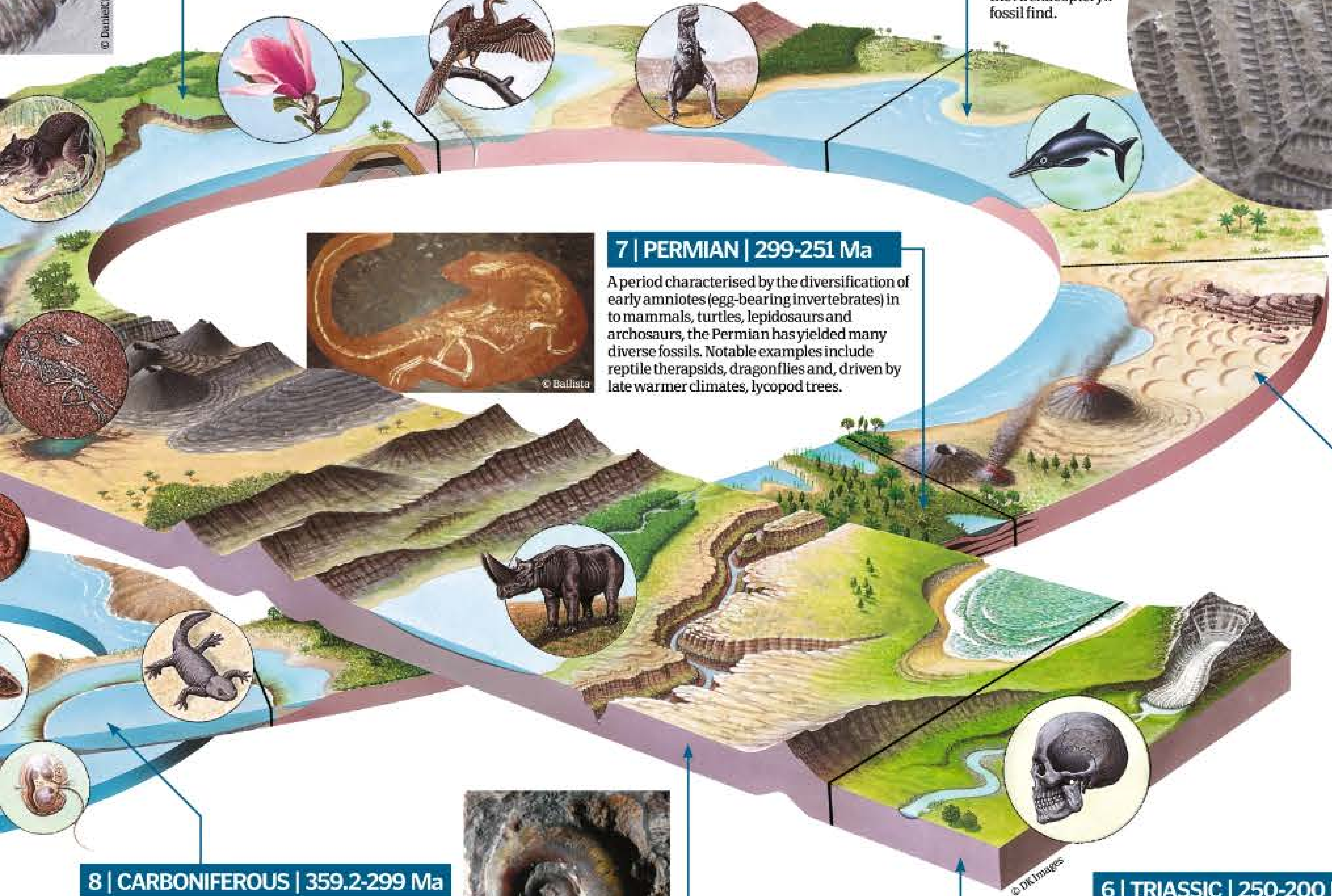
4 | CRETACEOUS | 145.5-65.5 Ma


© Petter Bockman

Fossils discovered from the Cretaceous indicate an explosion of insect diversification, with the first ants and grasshoppers evolving, as well as the dominance of large dinosaurs such as the colossal Tyrannosaurus rex. Mammals increased in diversity, however they remained small and largely marsupial.

5 | JURASSIC | 199.6-145.5 Ma

The period in Earth's history when the supercontinent Pangaea broke up in to the northern Laurasia and southern Gondwana, the Jurassic saw an explosion in marine and terrestrial life. The fossil record points to dinosaurs thriving, such as Megalosaurus, an increase in large predatory fish like Ichthyosaurus, as well as the evolution of the first birds – shown famously by the Archaeopteryx fossil find.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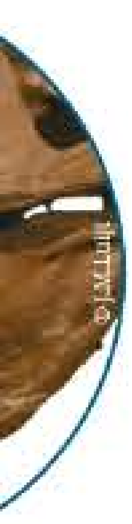
7 | PERMIAN | 299-251 Ma

A period characterised by the diversification of early amniotes (egg-bearing invertebrates) in to mammals, turtles, lepidosaurs and archosaurs, the Permian has yielded many diverse fossils. Notable examples include reptile therapsids, dragonflies and, driven by late warmer climates, lycopod trees.

8 | CARBONIFEROUS | 359.2-299 Ma

A period of significant glaciation, the Carboniferous saw the development of ferns and conifers, bivalve molluscs and a wide-variety of basal tetrapods such as labyrinthodontia. Notable fossilised finds include the seed ferns pecopteris and neuropteris.


© Dlloyd


© JM Luijt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2 | NEOGENE | 23.03-2.588 Ma

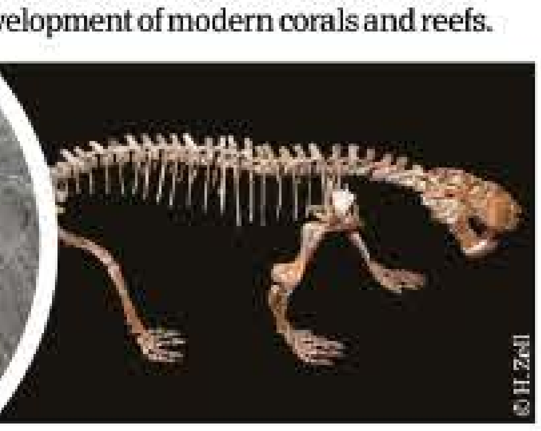
Covering 23 million years, the Neogene period's fossils show a marked development in mammals and birds, with many hominin remains excavated. The extinct hominid australopithecus afarensis – a common ancestor of the genus homo (that of modern humans) – is one of the most notable fossil finds, as exemplified in the specimens Lucy and Selam.

1 | QUATERNARY | 2.588-0.00 Ma

The most recent period in Earth's history, the Quaternary is characterised by major changes in climate, as well as the evolution and dispersement of modern humans. Due to the rapid changes in environment and climate (ie, ice ages), many larger mammal fossils have been discovered, including those of mammoths and sabre-toothed cats.

6 | TRIASSIC | 250-200 Ma

Beginning and ending with an extinction event, the Triassic period's fossils show the evolution of the first dinosaurs such as Coelophysis, a small carnivorous biped animal. Fossil evidence also shows the development of modern corals and reefs.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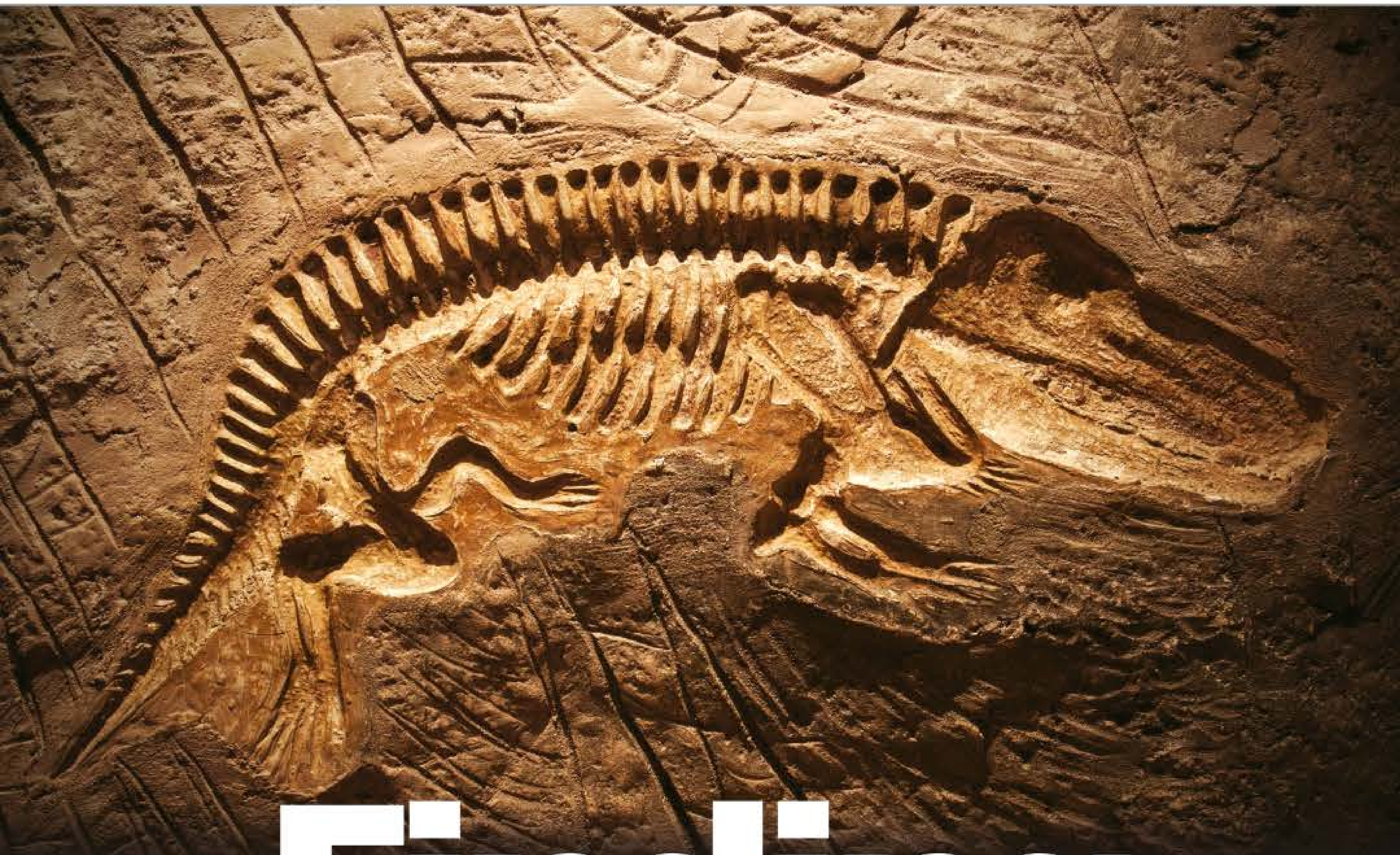


Finding fossils

How are prehistoric remains uncovered and what can scientists learn from them? Let us dig up the facts…

Ever since Mary Anning first began piecing together the fossils of Jurassic beasts in the early nineteenth century, scientists have been learning more and more about the dinosaurs that ruled the world millions of years ago. Buried deep beneath the ground for aeons, the remains of countless extinct creatures are waiting to be unearthed by palaeontologists, who can gradually unlock their secrets.

Dinosaurs and other prehistoric fossils have been discovered around the world for thousands of years, with reports of 'dragon bones' found in China more likely indicating some of the earliest dino finds. However, it wasn't until the brilliant scientists of the Enlightenment in the late-18th and early-19th centuries that it became clear just how old these ancient skeletons really were. Before long, fossil hunting became an obsession for naturalists and amateurs alike, with the strange extinct 'lizards' being discovered at sites all over the globe.

Though ground-penetrating radar now helps archaeologists identify hidden underground remains, modern palaeontologists still often rely on the same methods their 19th-century predecessors did: plain luck. Of course, through a greater understanding of geology, as well as by searching in so-called fossil hotspots, it's possible to predict where fossils will likely be found. Once a fossil site has been identified, the long and delicate process of unearthing the dino remains begins.

Digging for fossils can be as simple as sieving through sand and silt in the search for tiny teeth, or cracking open large rocks with a hammer and chisel to see what may be lying within. Hills, quarries, mountainsides and ravines are often prime locations for fossil finds, as the deep layers of rock have become exposed by millions of years of erosion. In these cases heavy diggers and drills are crucial to reach the finds. Dozens of scientists, students and even enthusiastic volunteers are employed with brushes and trowels during the course of an excavation. However, because of the delicate nature of specimens that are millions of years old, it can often take what must seem like another million to safely uproot an entire dinosaur skeleton.

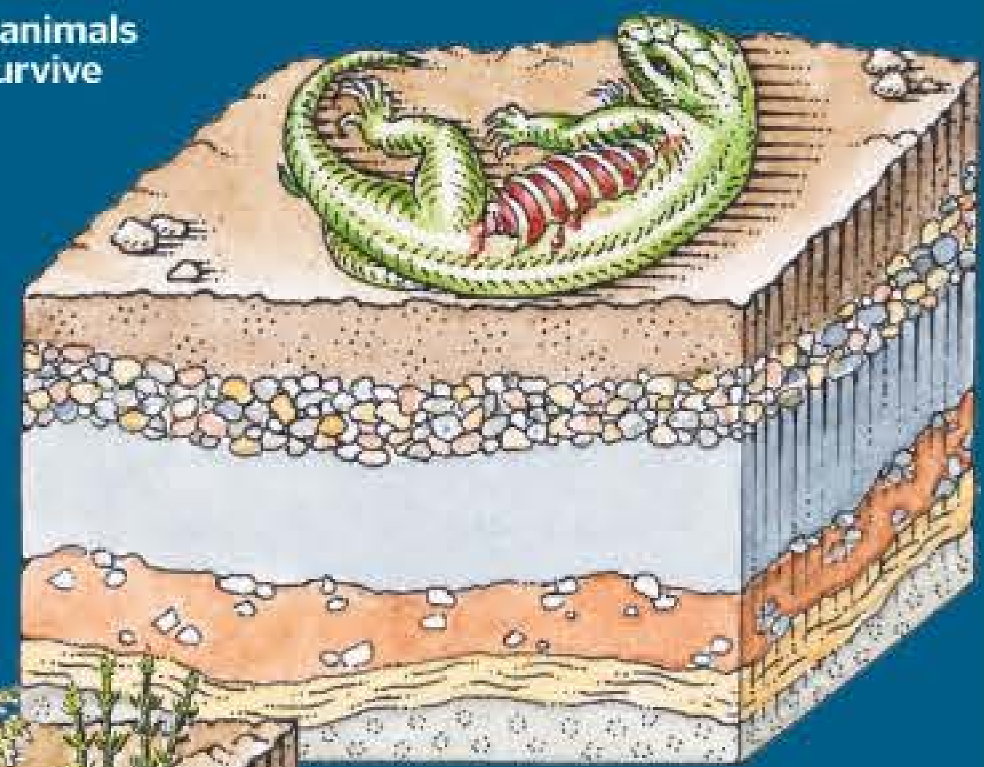
Of course, palaeontologists do much more than just dig up old bones. Mixing together the disciplines of geology and biology, palaeontology is the study of fossils to reveal the history of life on Earth. So, once the fossilised remains have been fully excavated, the real work can begin back in the lab. Here scientists painstakingly remove any residual earth and stone from the specimens in preparation for full analysis. Electron microscopes, CAT scanners and X-ray machines are all employed to gather as much information about the creature as possible.

By studying the shape, length and arrangement of each fossilised bone, palaeontologists have been able to determine not only what certain dinosaurs looked like and how they moved, but also what they ate. The discovery of indentations on fossilised arm bones similar to those found on modern birds has also indicated that many species of dinosaur were actually feathered.

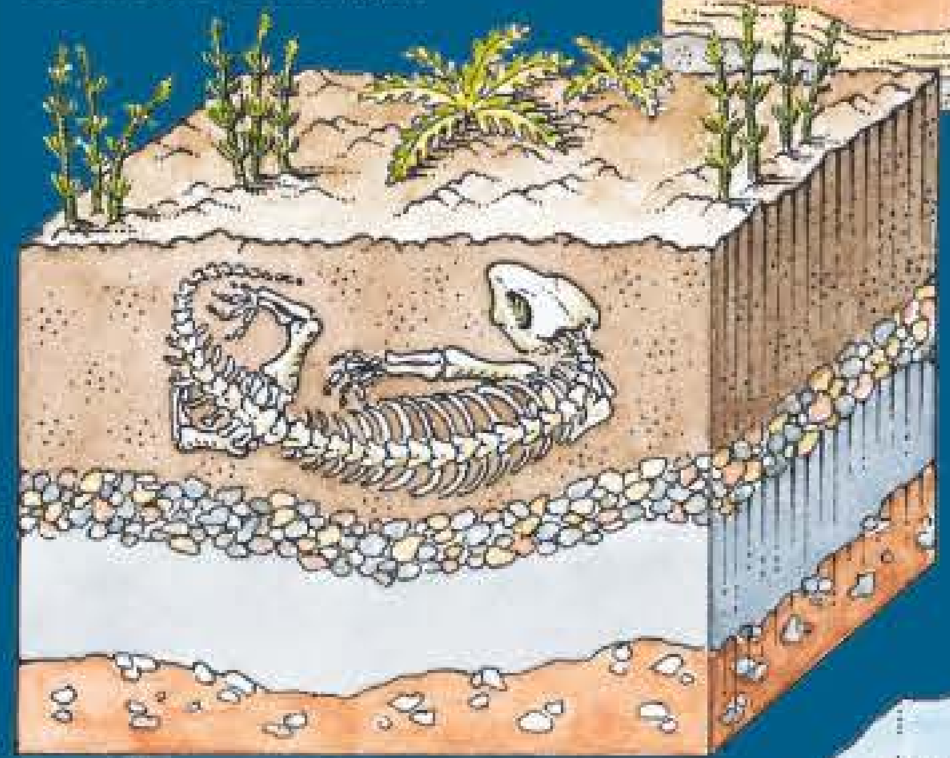
Bigger, stranger and ever-more unbelievable dino discoveries are being made all the time, each one challenging past theories and shedding new light on the distant land of the Mesozoic beasts. Thanks to the pioneering work of the scientists and enthusiasts of the past, each new fossil found could slot yet another piece of the prehistoric jigsaw into place.

How fossils form

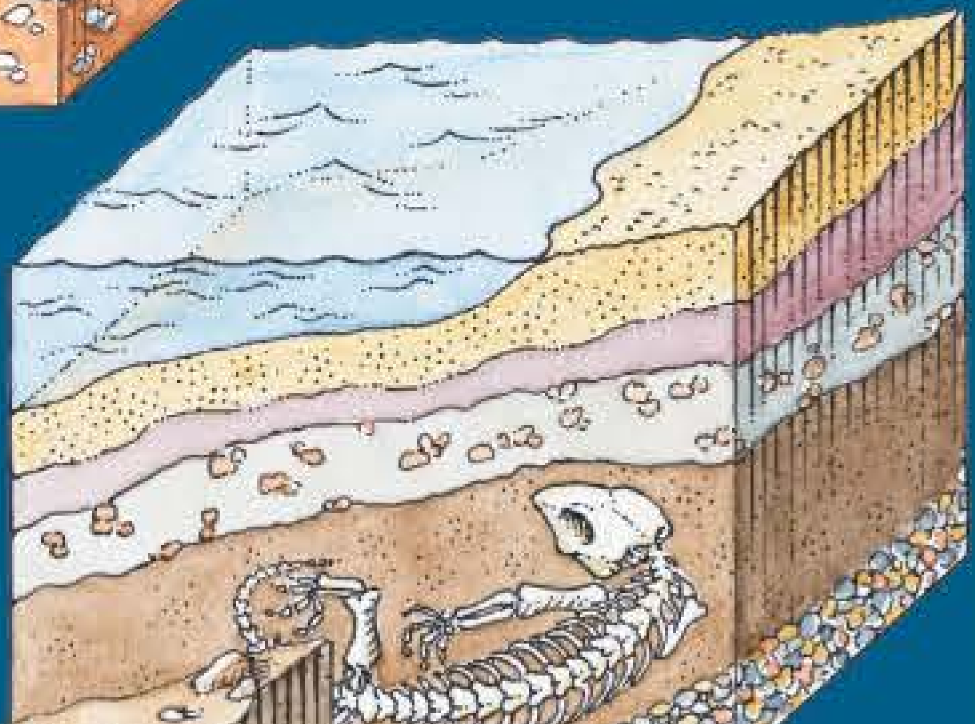
How do the remains of prehistoric animals become fossils, and why do they survive through the ages?



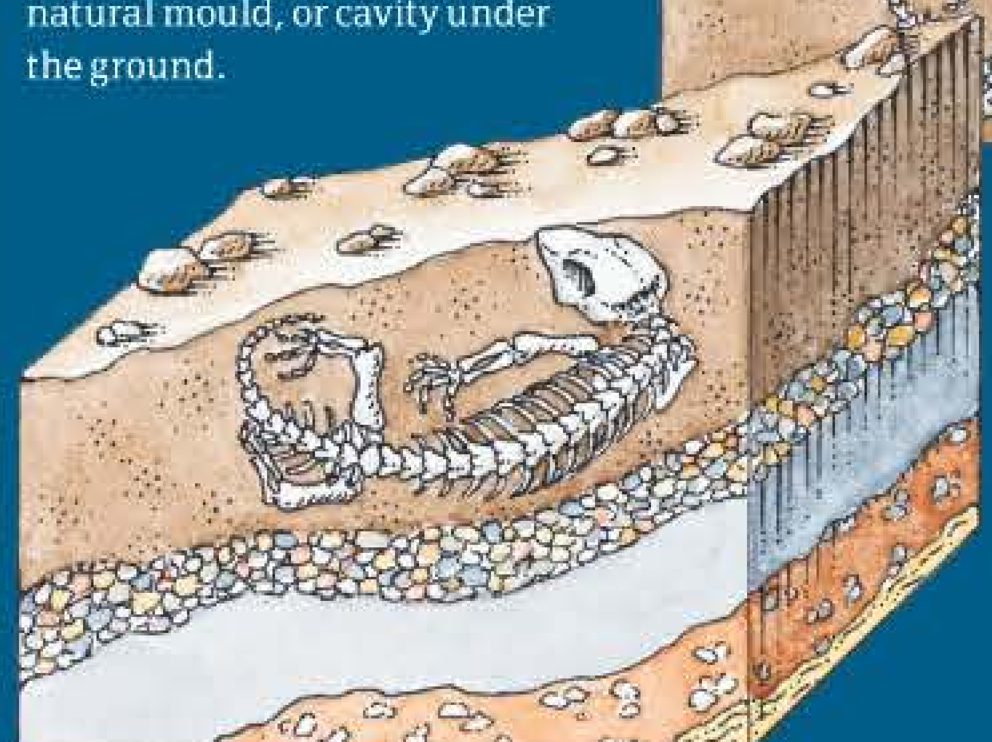
1 After death, a dinosaur's remains would often just rot and erode away completely, leaving not even a skeleton behind. However, in the right conditions, where the remains are kept safe from weather and hungry scavengers, the process of fossilisation can begin.



2 Over a long period of time, shifting sands, soil and sediment entirely cover the skeleton, encasing it in the ground. Any remaining soft tissue such as skin and organs, decays away entirely, leaving only the creature's bones. At this stage the remains are only partly fossilised.



3 As rising sea levels and shifting materials leave the skeleton further underground, the earth around the skeleton hardens under immense pressure. Eventually the bones entirely dissolve, leaving their shape behind in a natural mould, or cavity under the ground.



4 Over time, mineral deposits slowly gather in the creature's mould, chemically replacing the original bone. As sea levels recede away and materials shift around, the fossil draws closer to the surface. Eventually it can be found either entirely exposed or close to the topsoil.

Digging for dinosaurs

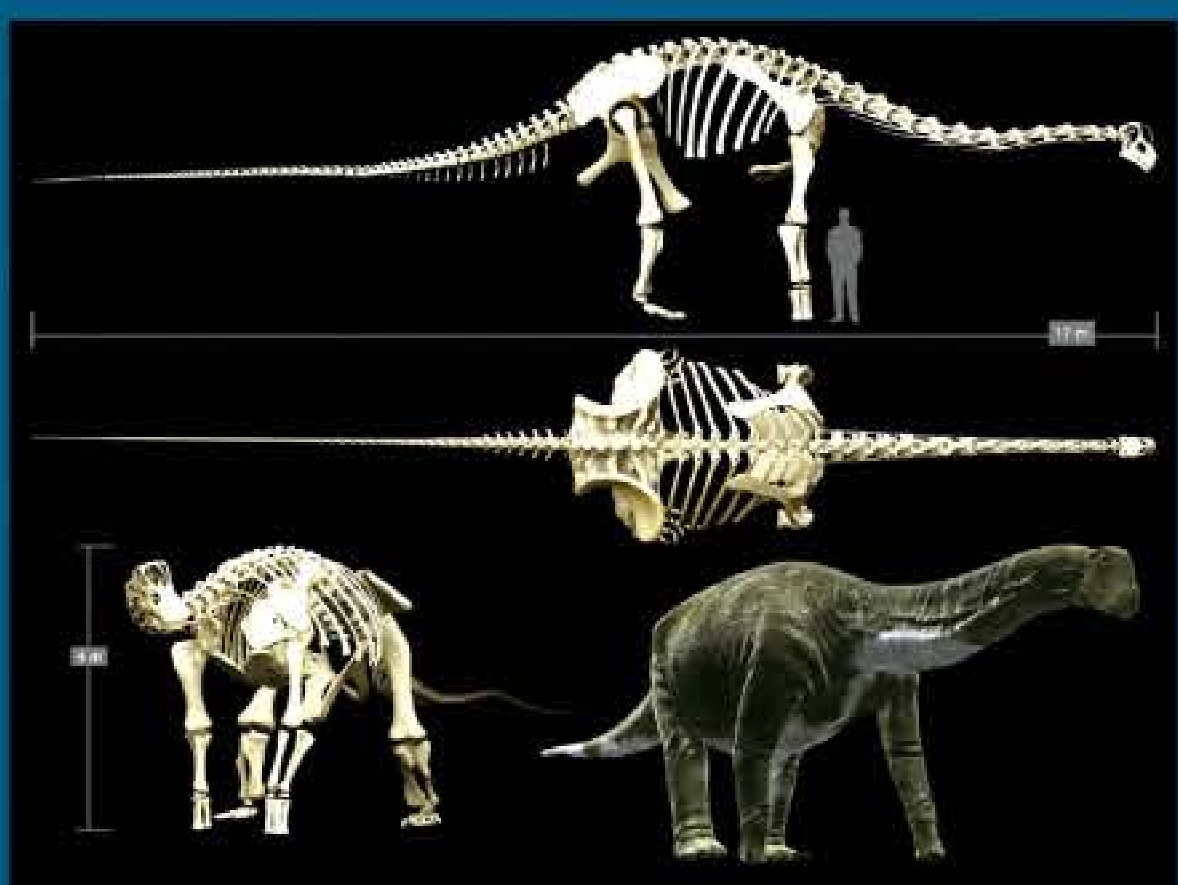
How palaeontologists discover and unearth prehistoric giants

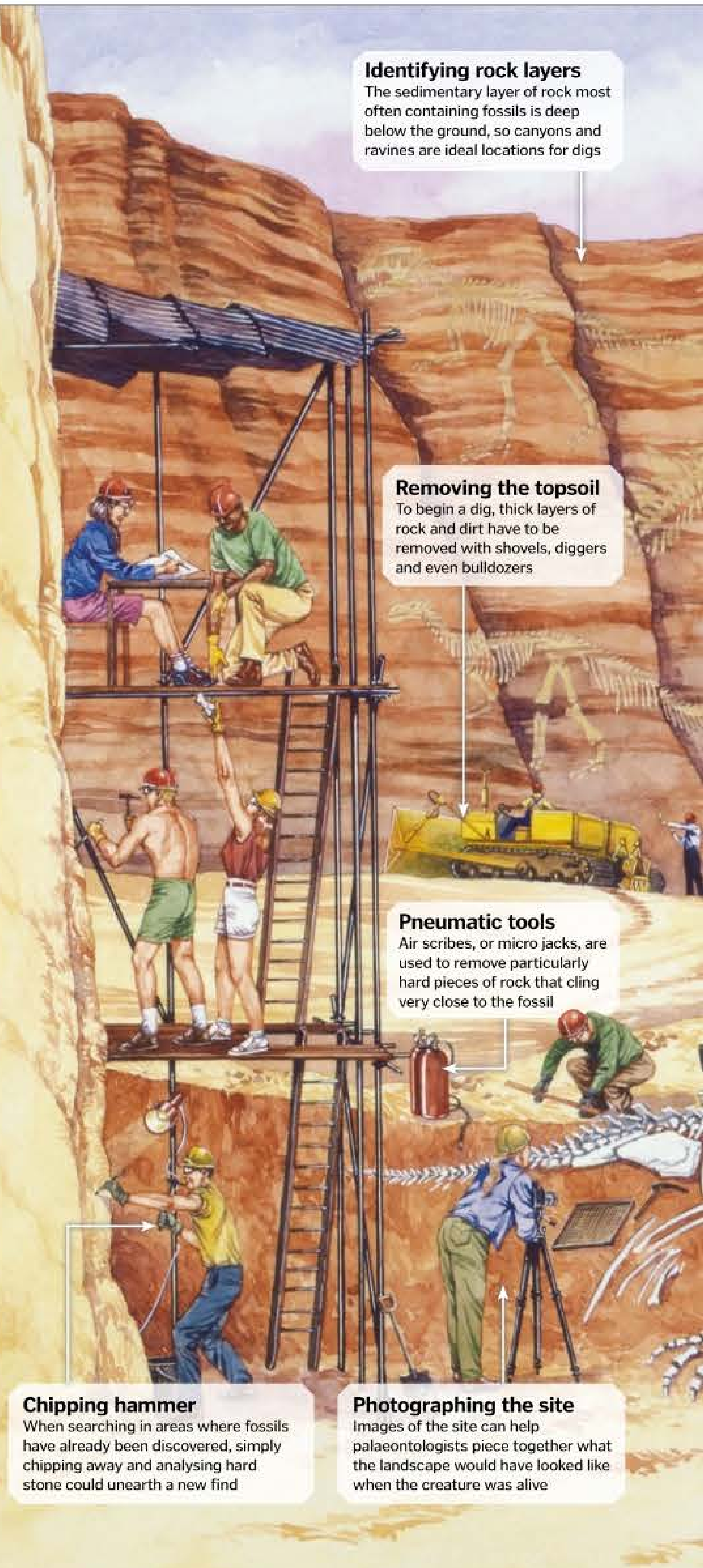
Bulldozers, hammers, chisels, drills and even dynamite – you'd be forgiven for thinking these were part of a construction-site inventory. In fact, they are the basic tools a palaeontologist will use to uncover the mysteries of the past. From removing tons of topsoil with diggers and other heavy machinery, to carefully clearing away clinging dust and debris with delicate brushes, the process of excavating a dinosaur skeleton can take many years.

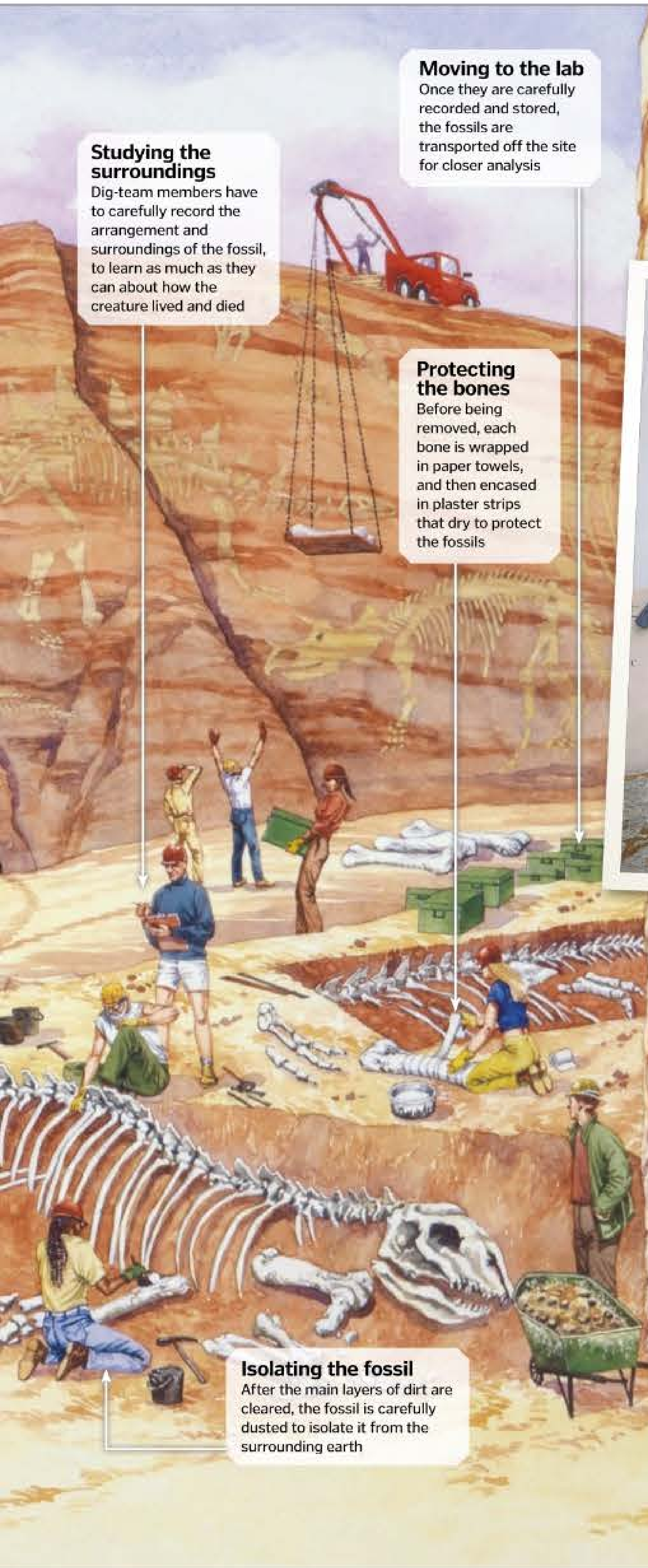
The largest dino fossil

Even in this ancient time when giants ruled the Earth, sky and sea, Dreadnoughtus schrani truly was a behemoth of a creature. Standing over two-storeys tall and weighing as much 60 tonnes, the remains of this beast were found by a team in Patagonia, Argentina, and have been dated back to over 77 million years ago. A member of the titanosaur sauropod group of dinosaurs, Dreadnoughtus was a plant-eater and is to date the largest known land animal ever to have lived.

Two Dreadnoughtus titanosaurs were found at the site, and it's believed the pair died in a massive flash flood, which would explain why their remains were so complete. The preservation of the skeletons enabled scientists to take full advantage of 3D-printing technology, scanning in each individual bone into a digital format for even greater scrutiny. This 3D rendering of Dreadnoughtus provided even greater insight into how it likely looked and moved.







Studying the surroundings
Dig-team members have to carefully record the arrangement and surroundings of the fossil, to learn as much as they can about how the creature lived and died

Moving to the lab
Once they are carefully recorded and stored, the fossils are transported off the site for closer analysis

Protecting the bones
Before being removed, each bone is wrapped in paper towels, and then encased in plaster strips that dry to protect the fossils

Isolating the fossil
After the main layers of dirt are cleared, the fossil is carefully dusted to isolate it from the surrounding earth

Tools of the trade

What do you need for a fossil dig?

Chisels
Chisel blades come in a range of sizes for either cracking apart larger stone or trimming away a rock face

Hammers
Crack and chipping hammers are essential for carefully removing and trimming hard rock. They are also needed for working with chisels

Sieve
Not all fossils come in huge sizes, so wire sieves are perfect for sifting through sand and silt for teeth and other small remains

Maps
If travelling to more remote locations, as well as for making reliable notes for future reference, a good map and compass are a must

Brushes
Small, soft bristles are ideal for working with delicate remains, while larger, harder brushes are best for removing thicker dust

Journals and reference
Accurately recording everything you find, where it's found, as well as referencing what it could be, is vital for making new discoveries

Where are the best spots to hunt dinosaur fossils?

Dinosaur fossils are found in among layers of sedimentary rocks, which are formed from compressed layers of silt and clay that have been deposited over periods of time. This means that the best places to find them tend to be in dry desert areas where the fossils are unlikely to have been covered by plant matter and soil.

As such, the largest number of fossils from the greatest variety of dinosaur species have been found in the fossil-hunting hotspots of North America and China, more specially places such as Wyoming in the USA, Nova Scotia in Canada and Chengjiang County in China.

Fossil sites have been found in other places around the world though, including around Victoria in Australia, Patagonia in Argentina and in Devon and Dorset in the UK, where the Jurassic Coast boasts 95 miles of Triassic, Jurassic and Cretaceous cliffs.

101 GIGANTIC FACTS ABOUT DINOSAURS

WE'VE DUG UP THE MOST ESSENTIAL DINOSAUR FACTS THAT EVERYONE SHOULD KNOW

01 The word 'dinosaur' means terrible lizard

The word 'dinosaur' was first used in 1841 by biologist Sir Richard Owen. It is from the Greek word 'deinos', meaning terrible or great, and 'sauros', meaning lizard.

Camarasaurus
Late Jurassic
North America

02 Dinosaurs were not lizards

Despite being named 'terrible lizards', dinosaurs were anatomically very different from other reptiles and are not that closely related.

Monolophosaurus
Mid Jurassic
China

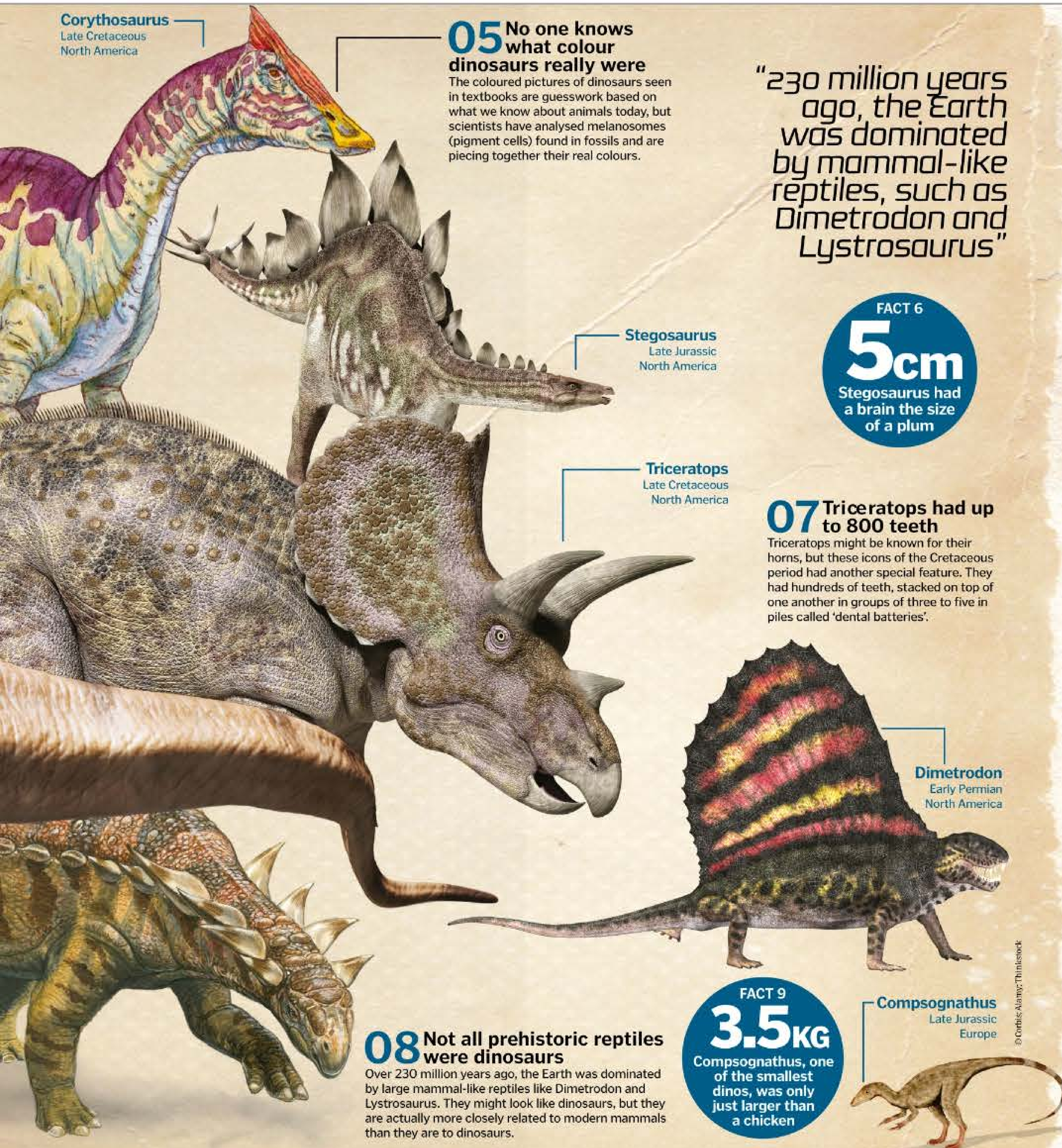
FACT 3
200 TONS
No dinosaur even came close to the weight of a blue whale

Deinonychus
Early Cretaceous
North America

Sauropelta
Early Cretaceous
North America

04 Cavemen never met the dinosaurs

The reign of the dinosaurs came to an end 66 million years ago, but humans have only been around for 200,000 years. Our ancestors did not share a world with the dinosaurs, but they did encounter sabre-toothed cats and woolly mammoths.



05 No one knows what colour dinosaurs really were

The coloured pictures of dinosaurs seen in textbooks are guesswork based on what we know about animals today, but scientists have analysed melanosomes (pigment cells) found in fossils and are piecing together their real colours.

> "230 million years ago, the Earth was dominated by mammal-like reptiles, such as Dimetrodon and Lystrosaurus"

FACT 6
5cm
Stegosaurus had a brain the size of a plum

07 Triceratops had up to 800 teeth

Triceratops might be known for their horns, but these icons of the Cretaceous period had another special feature. They had hundreds of teeth, stacked on top of one another in groups of three to five in piles called 'dental batteries'.

08 Not all prehistoric reptiles were dinosaurs

Over 230 million years ago, the Earth was dominated by large mammal-like reptiles like Dimetrodon and Lystrosaurus. They might look like dinosaurs, but they are actually more closely related to modern mammals than they are to dinosaurs.

FACT 9
3.5KG
Compsognathus, one of the smallest dinos, was only just larger than a chicken

Sauropods

These long-necked giants are among the largest animals to have ever lived

10 Sauropods were huge herbivores

The four-legged dinosaurs with long tails and necks are known as sauropods. The most common were Diplodocus and Camarasaurus.

11 Diplodocus had 15 vertebrae in its neck

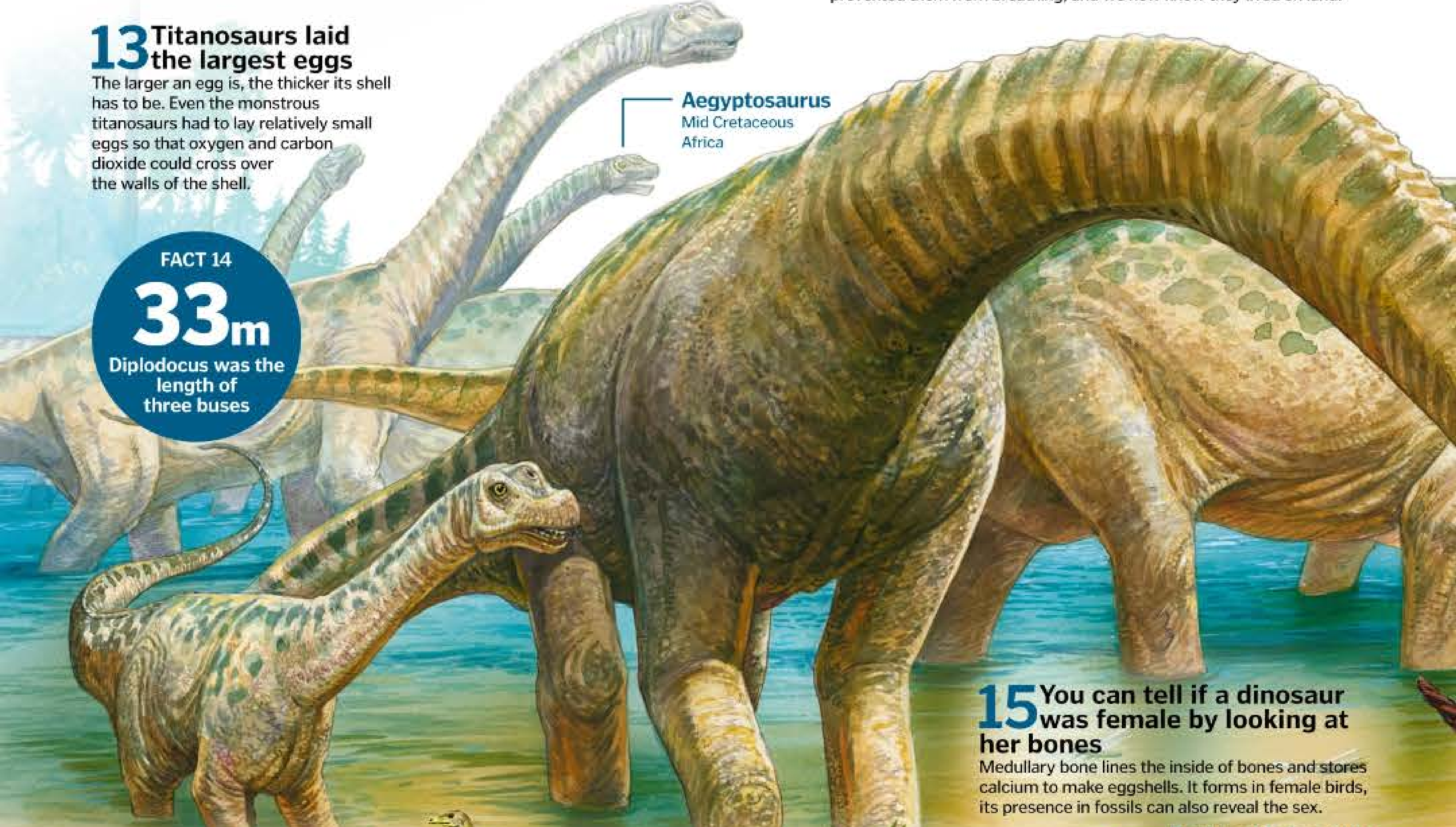
At least, we think it did – there are very few complete specimens. For comparison, a human has seven neck vertebrae.

12 Sauropods did not live in water

Early ideas about how sauropods like Diplodocus lived portrayed them walking underwater like hippos. They had nostrils on the top of their heads, and scientists thought they would use their necks like snorkels. However, with large bodies, the crushing weight of water would have prevented them from breathing, and we now know they lived on land.

13 Titanosaurs laid the largest eggs

The larger an egg is, the thicker its shell has to be. Even the monstrous titanosaurs had to lay relatively small eggs so that oxygen and carbon dioxide could cross over the walls of the shell.



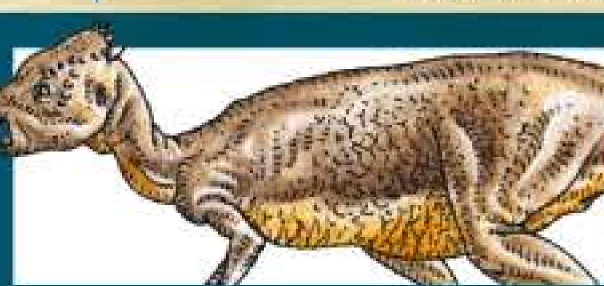
FACT 14

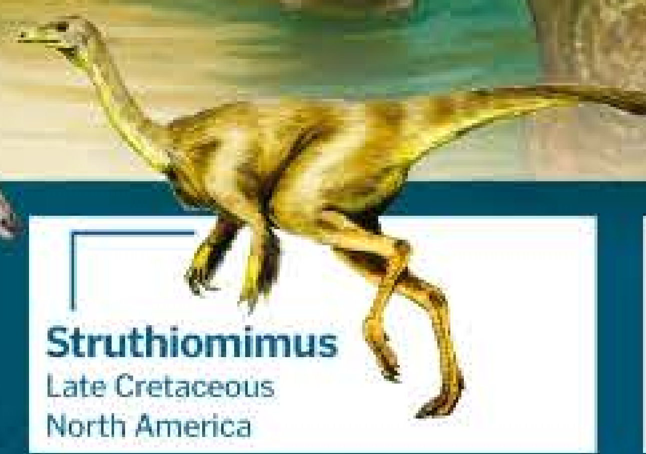
33m

Diplodocus was the length of three buses

15 You can tell if a dinosaur was female by looking at her bones

Medullary bone lines the inside of bones and stores calcium to make eggshells. It forms in female birds, its presence in fossils can also reveal the sex.





22 Hadrosaurs had duck-like bills

Hadrosaurs were the first dinosaurs found in North America, and since the nineteenth century, hundreds have been unearthed. These herbivores had a very distinctive appearance, with duck-like beaks adapted for clipping vegetation, and crested heads that might have helped to transmit sounds over long distances.

23 Ornithomimids looked and lived like ostriches

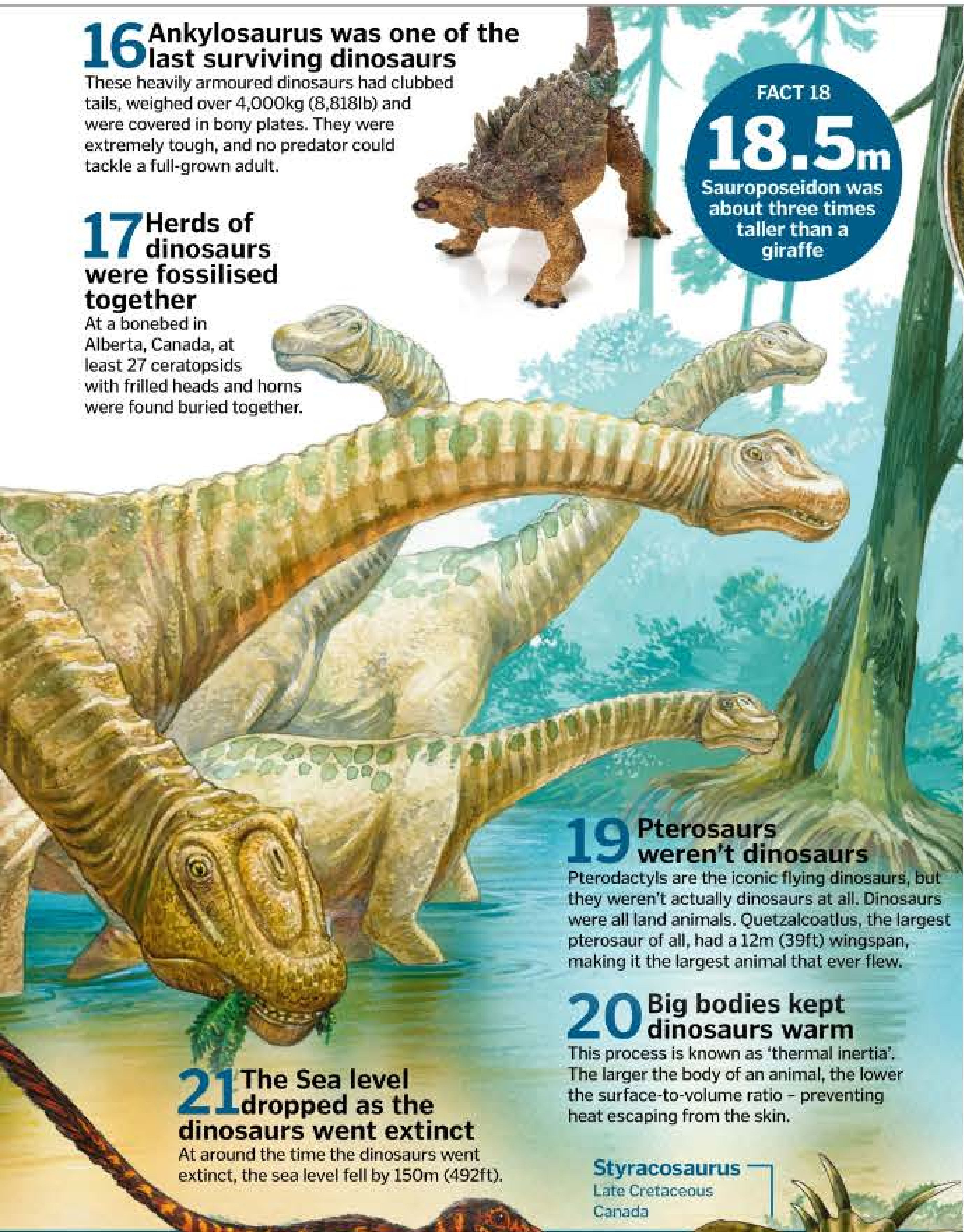
Ornithomimid means 'bird mimic', and these two-legged dinosaurs really do look familiar. They had long, muscular legs, large, rounded bodies and long necks with small heads. Like modern ostriches, these dinosaurs were extremely fast on their feet.

24 Dinosaurs didn't have two brains

Stegosaurus had a tiny brain, but at the base of its spine there was an enlarged space. Scientists once thought it might have housed a second, larger brain to control its legs, but this idea has been discredited as birds have a similar opening to store the energy-rich substance glycogen.

25 Pachcephalosaurs had thick skulls

Pachycephalosaur means 'thick-headed lizard'. The bone at the top of their skull could be up to 25cm (10in) thick, and their faces were covered in bumps and spikes. These dramatic features could have been for fighting, or they might just have been for show, like the antlers on modern deer.



16 Ankylosaurus was one of the last surviving dinosaurs

These heavily armoured dinosaurs had clubbed tails, weighed over 4,000kg (8,818lb) and were covered in bony plates. They were extremely tough, and no predator could tackle a full-grown adult.

17 Herds of dinosaurs were fossilised together

At a bonebed in Alberta, Canada, at least 27 ceratopsids with frilled heads and horns were found buried together.

FACT 18

18.5m

Sauroposeidon was about three times taller than a giraffe

19 Pterosaurs weren't dinosaurs

Pterodactyls are the iconic flying dinosaurs, but they weren't actually dinosaurs at all. Dinosaurs were all land animals. Quetzalcoatlus, the largest pterosaur of all, had a 12m (39ft) wingspan, making it the largest animal that ever flew.

20 Big bodies kept dinosaurs warm

This process is known as 'thermal inertia'. The larger the body of an animal, the lower the surface-to-volume ratio – preventing heat escaping from the skin.

21 The Sea level dropped as the dinosaurs went extinct

At around the time the dinosaurs went extinct, the sea level fell by 150m (492ft).

Sinornithosaurus
Early Cretaceous
China

Styracosaurus
Late Cretaceous
Canada

26 Dinosaurs had feathers

Despite what you might see in textbooks, museums and even in this bookazine, we now know that most dinosaurs were not all scaly and bald. We have known for a while that the two-legged theropods had feathers, but in 2014 a very distantly related beaked dinosaur found in Siberia was also found to have feathers, suggesting scales were replaced early in dinosaur evolution.

27 Ceratopsians had horned faces

The most famous ceratopsian is Triceratops, but there were other dinosaurs with horns and frills. These huge herbivores started to appear around 160 million years ago, and it is thought the frill was used as protection against predators, to impress potential mates and as a radiator to get rid of excess heat.

Nests & eggs

28 All dinosaurs laid eggs

Dinosaurs all reproduced by laying eggs like modern-day birds, and some of the hatchlings were thousands of times smaller than the full-grown adults.

29 Some dinosaurs cared for their young

Adult Psittacosaurus have been found alongside the fossilised remains of their young, and the bones of older babies have been found in the nests of Maiasaura, indicating that they probably helped to raise their young.

30 The largest dinosaur egg was over 60cm long

The largest dinosaur eggs were found in Mongolia in the 1990s, and measured around 45cm (17.7ft) across. Compared to the size of the adults, they are still surprisingly small.

31 Some of the best dinosaur fossils are babies

A 113-million-year-old fossilised baby dinosaur found in Italy still contains traces of preserved soft tissue, including intestines and tail muscles.

32 Baby dinosaurs grew rapidly

Sauropods like Diplodocus weighed a tiny 5kg (11lb) at birth, and grew to 10,000 times their size within just 30 years. Fossilised embryos show sauropod bones filled with blood vessels, bringing nutrients to allow rapid growth.

33 There are two main types of dinosaur egg

Dinosaur eggs can be divided into two main categories – spheroidal and elongated. Rounder eggs were laid by herbivores such as sauropods, while elongated, bird-like eggs were laid by theropods.

34 Oviraptors didn't steal eggs

The name 'Oviraptor' means egg thief, but these dinosaurs weren't criminals. They were actually devoted parents, and fossilised nests found in Mongolia show they arranged their eggs in spiral layers.

Tyrannosaurus rex

35 You probably couldn't outrun a Tyrannosaurus

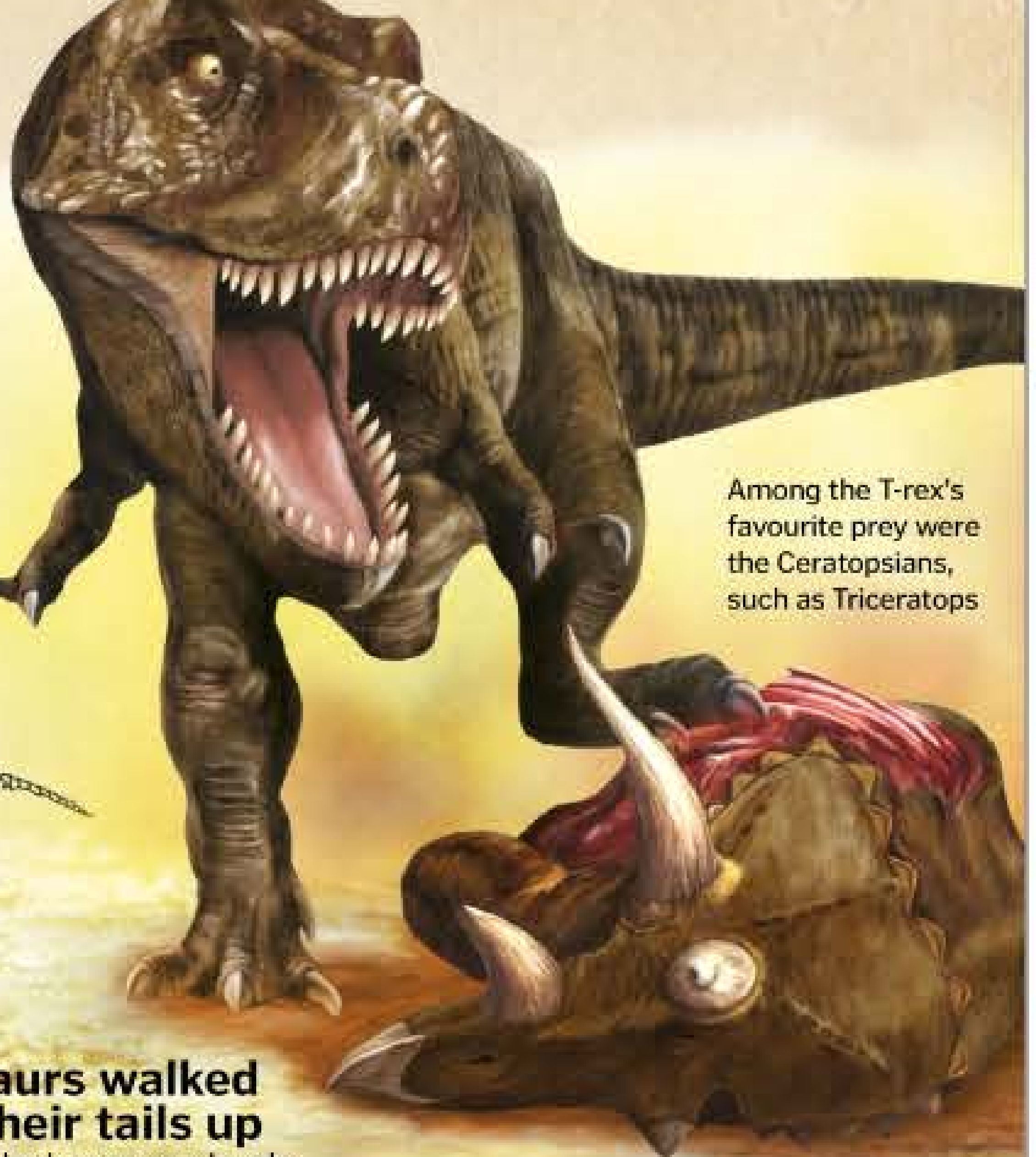
Computer simulations of T-rex running suggest that it had a top speed of around 29kmh (18mph). Not quite fast enough to catch up with a car, like in Jurassic Park, but quick enough to catch any human that's not an athlete.

36 The largest T-rex fossil is called Sue

Complete dinosaur fossils are incredibly rare, but there is one T-rex specimen that stands out from the rest. Sue is over 12.8m (40ft) long and stands over 3.9m (13ft) high. She is on display at the Chicago Field Museum and is the most complete specimen ever recovered.

37 Stegosaurus never met Tyrannosaurus

Despite being depicted together, these two would never have been in the same place at the same time. Stegosaurus lived during the Jurassic period and went extinct around 80 million years before T-rex first appeared at the end of the Cretaceous period.



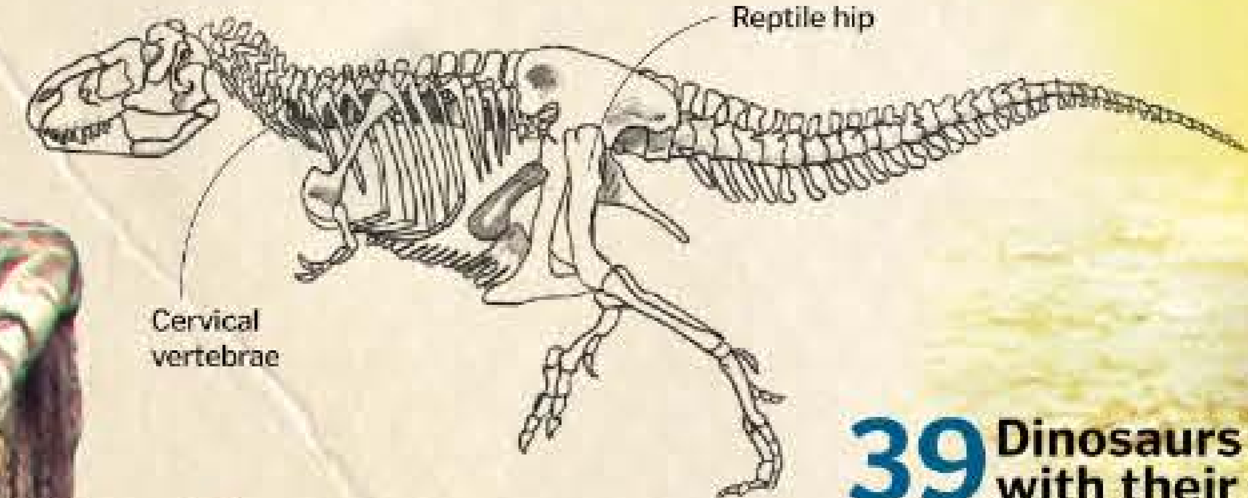
Among the T-rex's favourite prey were the Ceratopsians, such as Triceratops

Head

It measured 1.5m (4.9ft) long, and had eye and nose cavities. The skull was of thick and heavy bone, although in some points it was pretty flexible.

38 Some dinosaurs had a wishbone

The 'V'-shaped wishbone you find in your Sunday roast is also present in meat-eating theropods such as T-rex.



39 Dinosaurs walked with their tails up

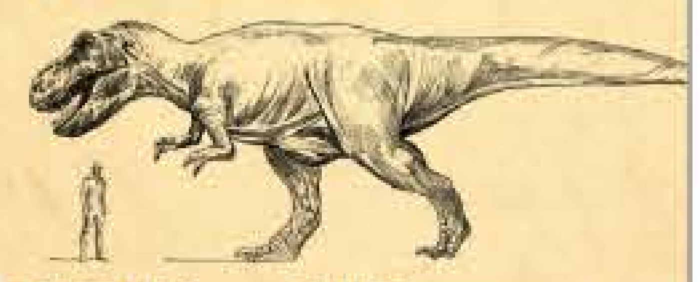
Dinosaurs like T-rex had enormous heads, and used their tails as a counterweight, holding them up for balance.

40 The meat-eating dinosaurs were all theropods

T-rex, Allosaurus and Deinonychus belonged to a group of dinosaurs known as theropods. Some members of this group are the largest carnivores ever to have walked the Earth.

DID YOU KNOW? *Most dinosaur fossils have pieces missing, and are reconstructed using similarities with other related species*

Data sheet



LENGTH 12.5m
WEIGHT 5,000kg
DIET Carnivorous
GENUS Tyrannosaurus
CLASSIFICATION Theropoda; Coelurosauria; Tyrannosauridea

41 T-rex had teeth the size of bananas

The largest Tyrannosaurus rex teeth measured 30cm (12in) in length. There has been much debate as to what they were used for, but scientists generally agree that T-rex was both a hunter and a scavenger. Broken T-rex teeth found in the fossilised tailbones of Hadrosaurs indicate that hunts weren't always successful.

42 T-rex had stronger arms than human beings

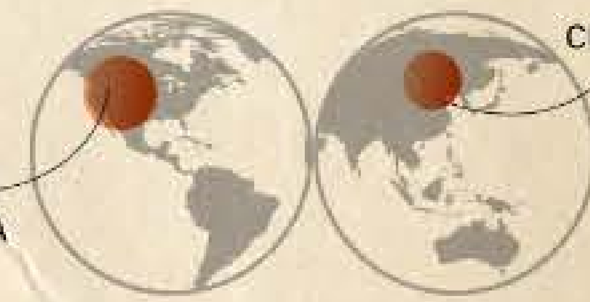
T-rex is often ridiculed for its little arms, but they were much stronger than you imagine. They were used for grasping prey, could move rapidly and were capable of lifting around 200kg (440lb), more than three times as much as an adult man.

43 The most expensive fossil is worth more than $8 million

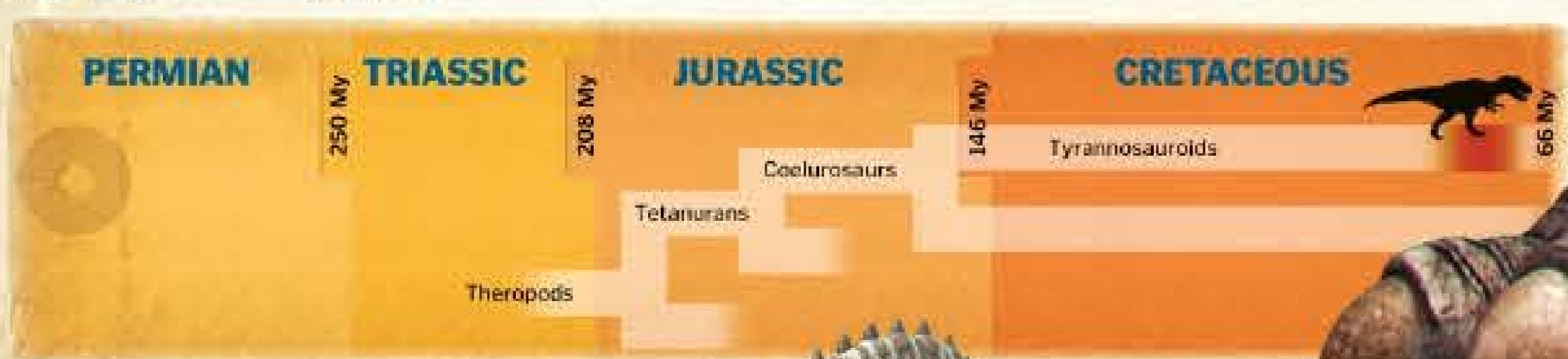
The famous Tyrannosaurus rex fossil known as Sue fetched $8.36 million at auction back in 1997 and is likely to be worth significantly more than that today.

Found in...

The T-rex was found in what is now North America, just like its cousins the Daspletosaurus, the Gorgosaurus and the Albertosaurus. The Tarbosaurus and the Guanlong, a primitive tyrannosaur of the Jurassic period, were discovered in Asia.



Phylogenetic tree

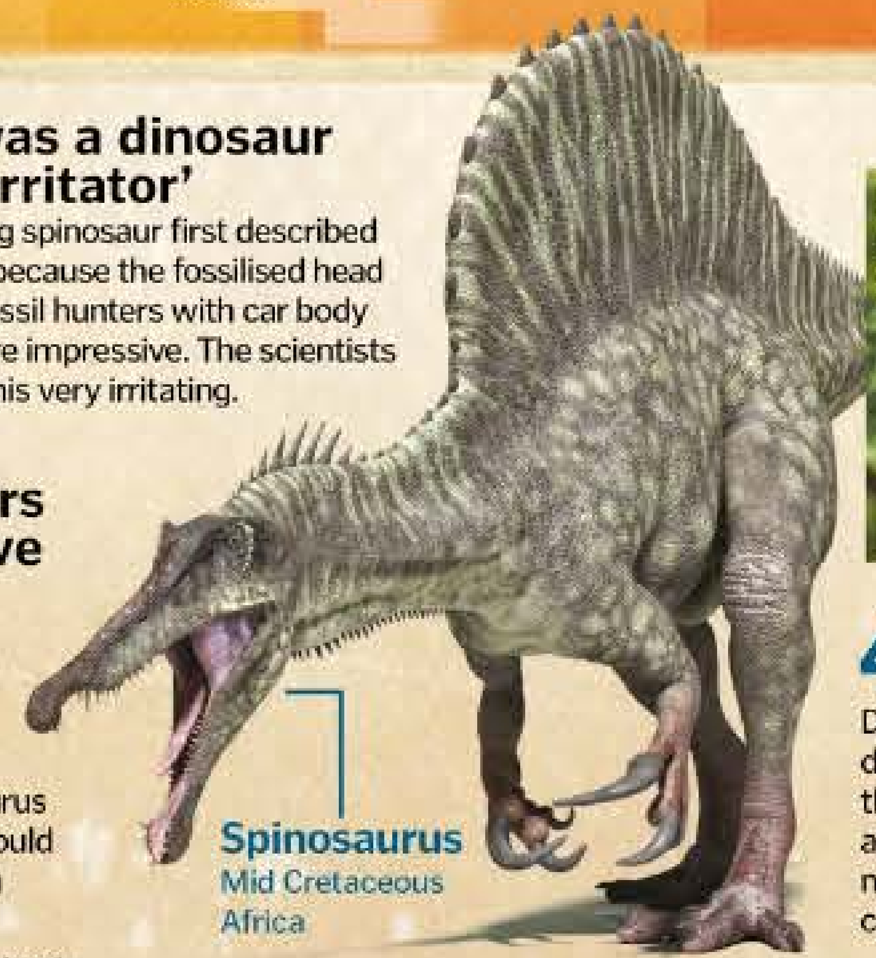


44 There was a dinosaur called 'Irritator'

Irritator was a fish-eating spinosaur first described in 1996. It got its name because the fossilised head had been modified by fossil hunters with car body filler to make it look more impressive. The scientists understandably found this very irritating.

45 Dinosaurs didn't live in the sea

Dinosaurs were land animals and were not closely related to the famous sea-dwelling Plesiosaur, but Spinosaurus was semi-aquatic and could run along the riverbed in pursuit of food.



Spinosaurus
Mid Cretaceous
Africa

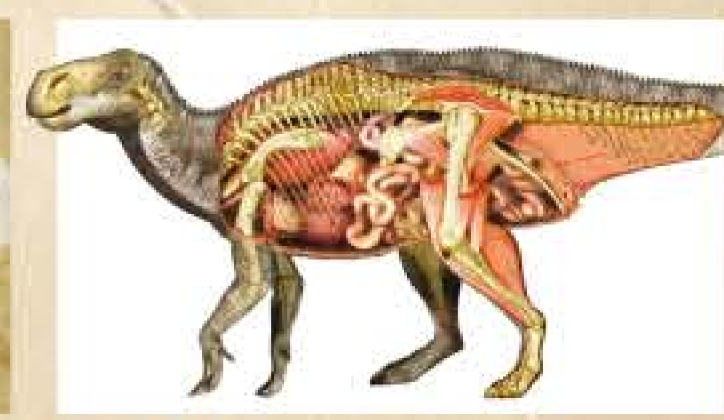
Archaeopteryx
Late Jurassic
Germany

46 No dinosaur could fly

Dinosaurs were all land-dwelling reptiles, and despite the fact that they are the ancestors of modern birds, none of them could fly. They could probably glide, though.

47 Archaeopteryx is the first fossil evidence of evolution

Archaeopteryx was the first feathered dinosaur to be discovered, linking birds and dinosaurs. The breakthrough came in 1861, just two years after Charles Darwin published his theory of evolution.



48 Dinosaurs were neither warm nor cold blooded

It was long thought that dinosaurs were cold blooded, like reptiles, but new evidence suggests that they were mesothermic – able to burn energy to make some body heat, but not warm blooded like mammals.

Classification

Dinosaurs can be split into two major groups, with many more subdivisions

49 The meat-eating dinosaurs walked on two feet

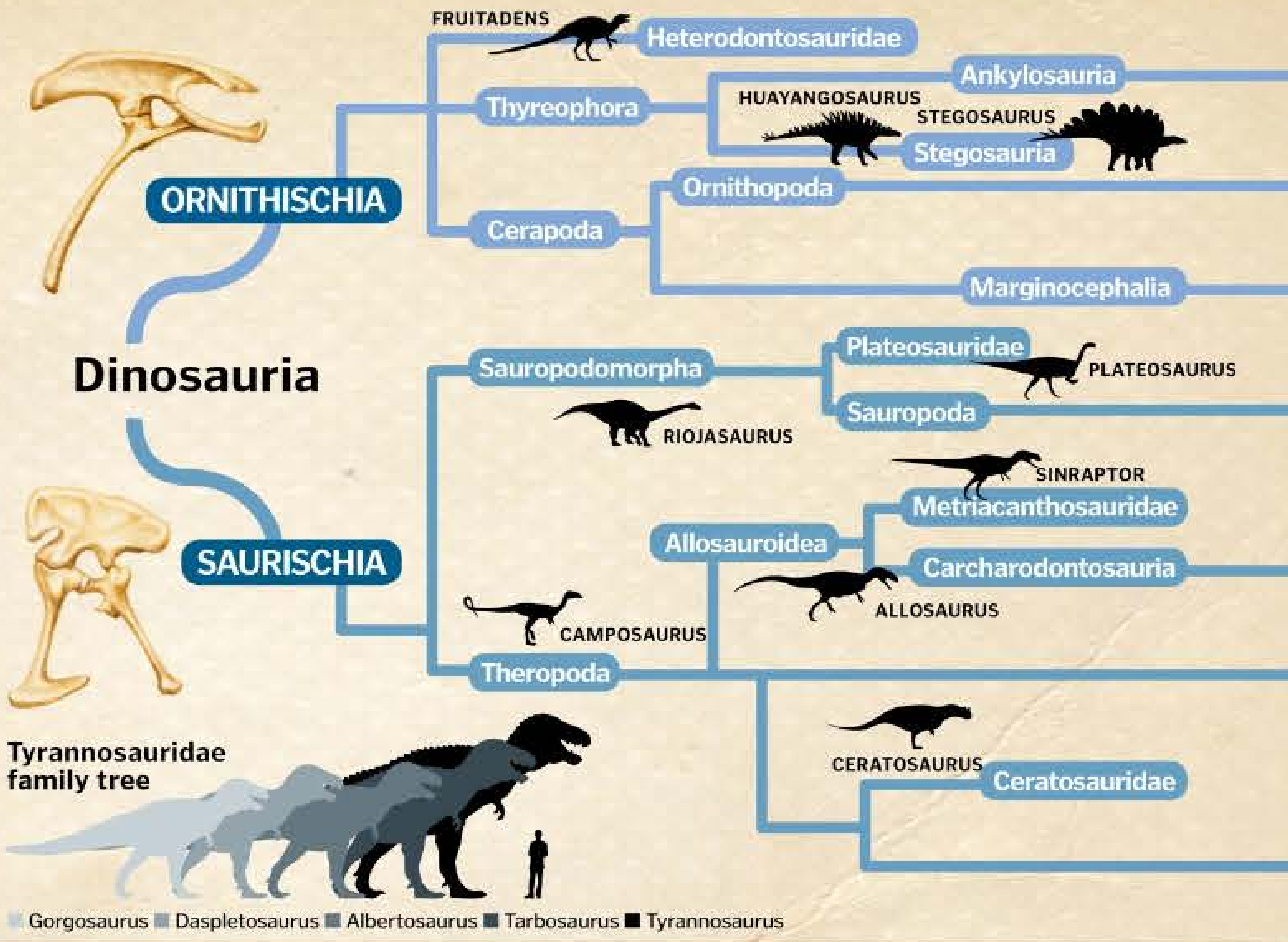
All the carnivorous dinosaurs were theropods (although not all theropods were carnivores) and walked upright on their two hind legs. They typically had hollow bones, three main fingers on each hand and foot, and sharp, curved teeth and claws used for hunting and eating.

50 Dinosaurs either had lizard hips or bird hips

Dinosaurs can be divided into two major groups based on their hipbones. The Ornithischia, or 'bird-hipped' dinosaurs had a pubic bone that pointed toward the tail, and the Saurischia, 'lizard-hipped' dinosaurs pointed toward the head. Interestingly, birds evolved from lizard-hipped dinosaurs.

51 Most dinosaurs ate plants

Dinosaurs are often portrayed as fearsome hunters, but the majority of species were herbivores. Even some of the ferocious-looking theropods actually ate plants and used their sharp claws for digging.



56 Dinosaurs lived during the Mesozoic Era

Dinosaurs ruled the Earth for 165 million years, in a time period known as the Mesozoic Era. This era can be split into three periods, Triassic, Jurassic and Cretaceous

57 Dinosaurs first appeared 230 million years ago

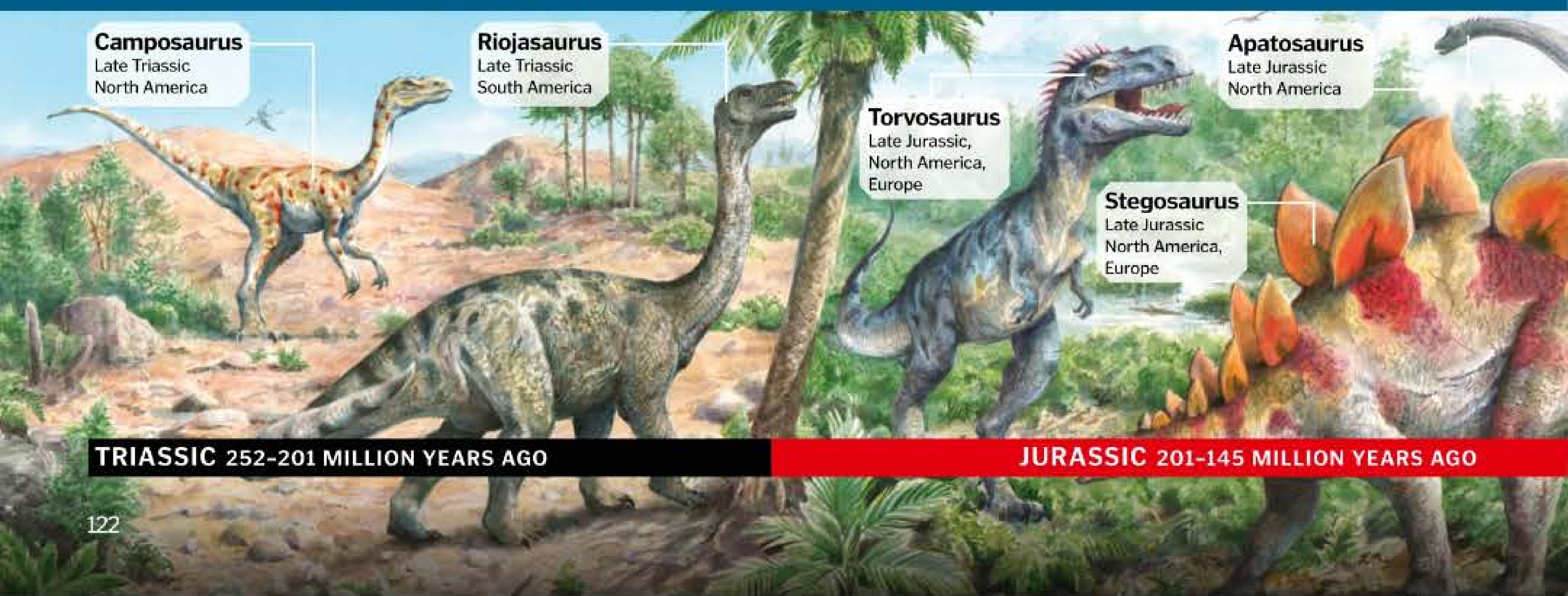
Dinosaurs evolved during the Triassic period, between 250 and 200 million years ago. The warm, dry conditions were perfect for breeding reptiles.

58 Volcanic eruptions contributed to the extinction of the dinosaurs

Huge lava flows are present in the fossil record for about 500,000 years before the extinction of the dinosaurs, and many scientists think eruptions contributed to their extinction by filling the air with a thick cloud of ash.

59 Early dinosaurs lived on the continent of Pangaea

When dinosaurs first appeared, the landmasses of the Earth were joined into a supercontinent called Pangaea. This later fractured into two continents – Laurasia and Gondwana.



52 There were more than 700 species of dinosaur

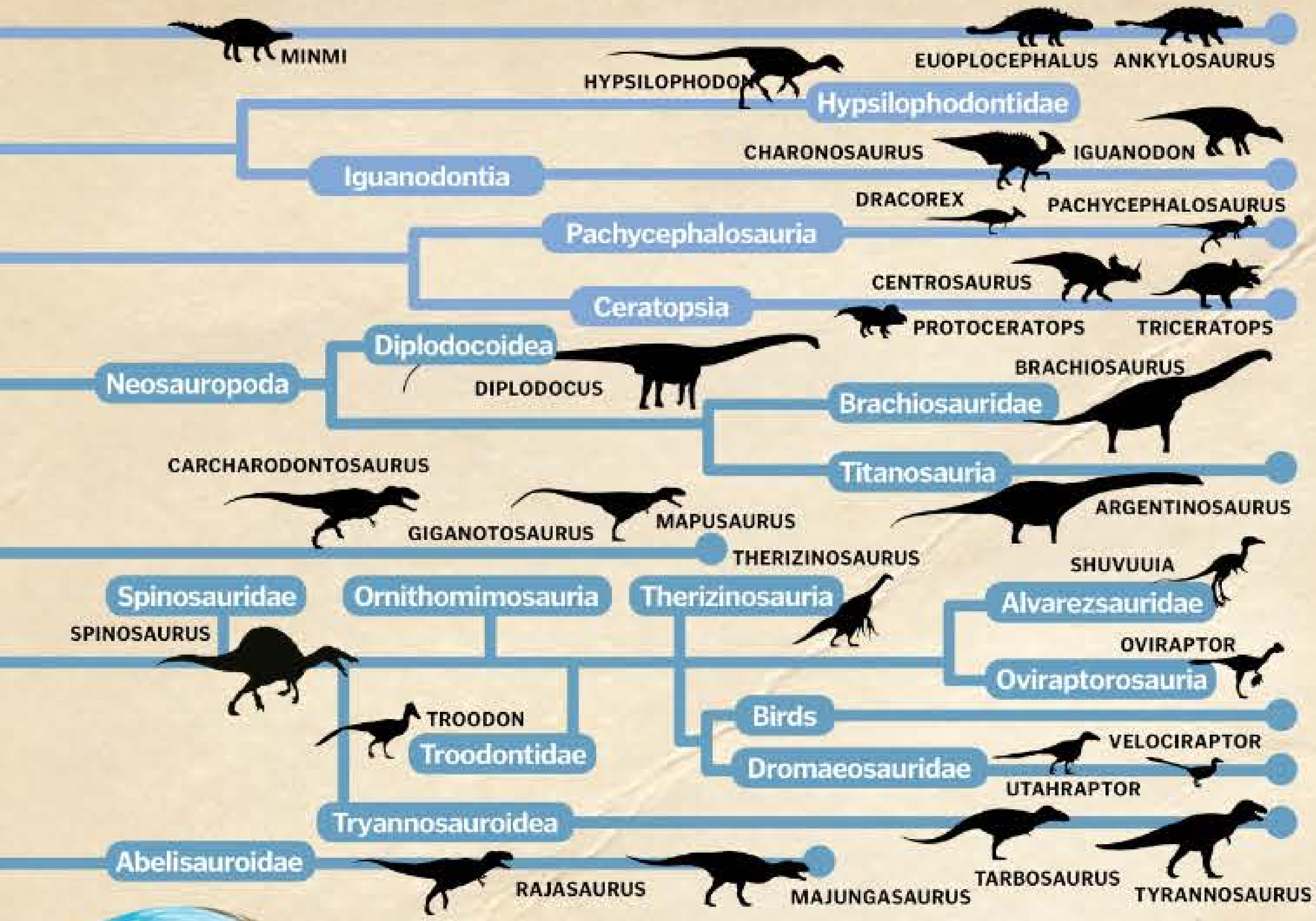
To date, over 700 species of dinosaur have been identified, but only around 300 have been confirmed as entirely unique. There are more yet to be found, so this number will continue to change.

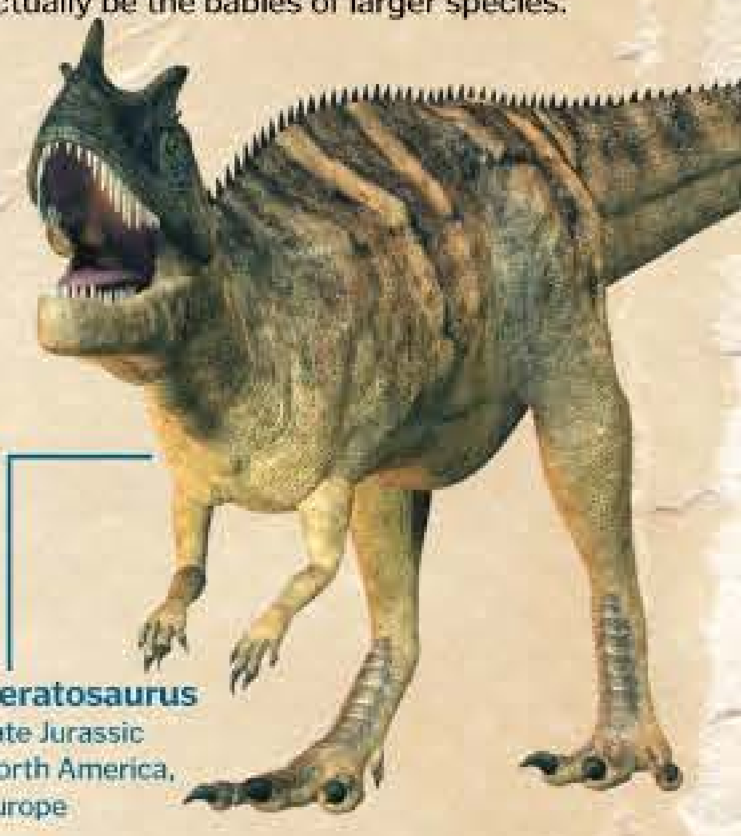
53 There are hundreds of dinosaurs yet to be found

It is estimated that we have only found around a tenth of the dinosaur species that ever existed. Some are buried in rocks we cannot reach, while others lived in areas where conditions did not favour fossil formation.

54 There were fewer dinosaur species than we thought

Hundreds of species of dinosaur have been named, but few baby dinosaurs have been found. Scientists have reviewed the evidence and have found that some smaller species might actually be the babies of larger species.





Ceratosaurus
Late Jurassic
North America, Europe

55 Dinosaurs are still alive today

In the 19th century the fossilised remains of a feathered dinosaur called Archaeopteryx were discovered, and since then evidence linking dinosaurs to birds has stacked up. It is thought that early birds started to evolve from the carnivorous theropods in the late Jurassic, and a few managed to survive the mass extinction, giving rise to the bird species we see today.

60 Sea levels were at an all-time high in the Cretaceous

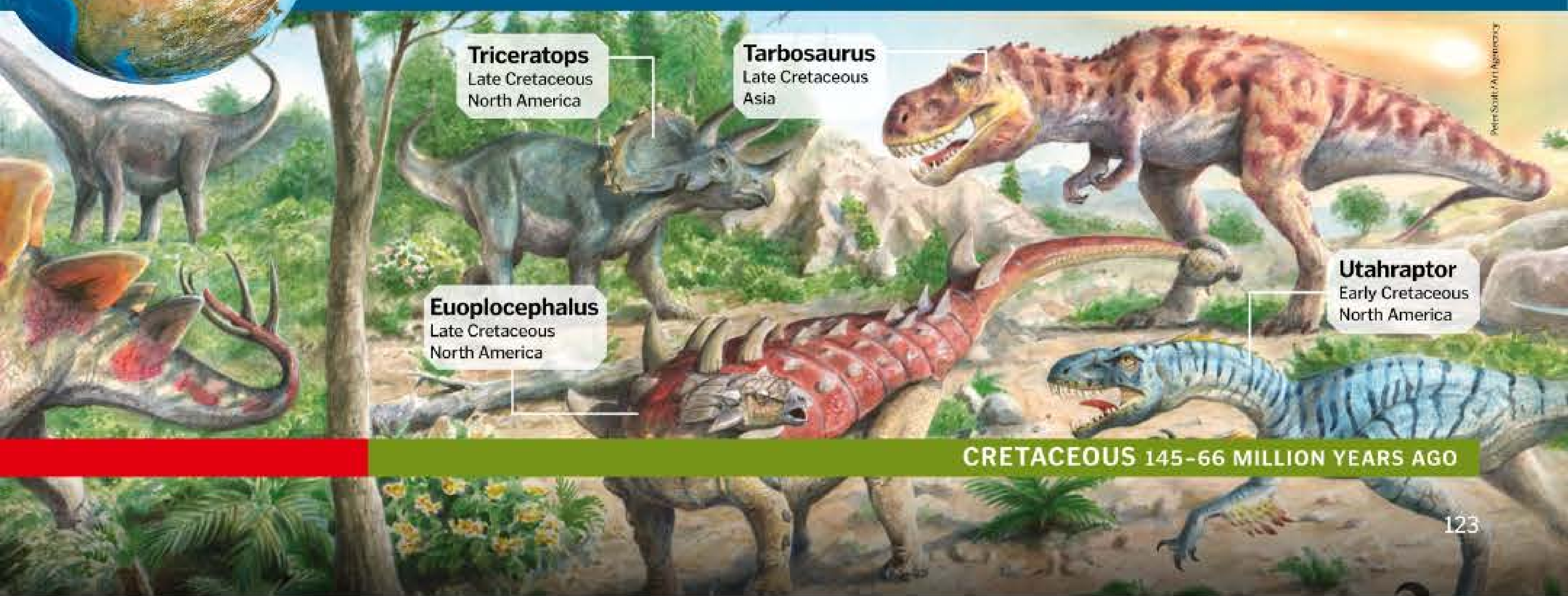
During the Cretaceous period, sea levels rose and fell dramatically, and large areas of land disappeared under water. At times the sea was 100-250m (330-820ft) higher than it is today.

61 High oxygen levels fuelled fires during the extinction event

During the Cretaceous period, oxygen levels in the atmosphere were much higher than they are now, which may have helped to fuel fires after the famous meteor impact 66 million years ago, contributing to the mass extinction.

62 They experienced more than one mass extinction

There was a mass extinction at the end of the Triassic period, when many land animals died out, leaving room for the evolution of some of the giants of the dinosaur world.



Triceratops
Late Cretaceous
North America

Tarbosaurus
Late Cretaceous
Asia

Euoplocephalus
Late Cretaceous
North America

Utahraptor
Early Cretaceous
North America

63 Armoured dinosaurs are known as 'Thyreophora'

Stegosaurus and Ankylosaurus are famous for their armour plating and were members of a group of dinosaurs called Thyreophora. Anklosauria were the most heavily armoured and had bony plates, spikes and clubbed tails.

64 Dinosaur's legs are positioned beneath their bodies

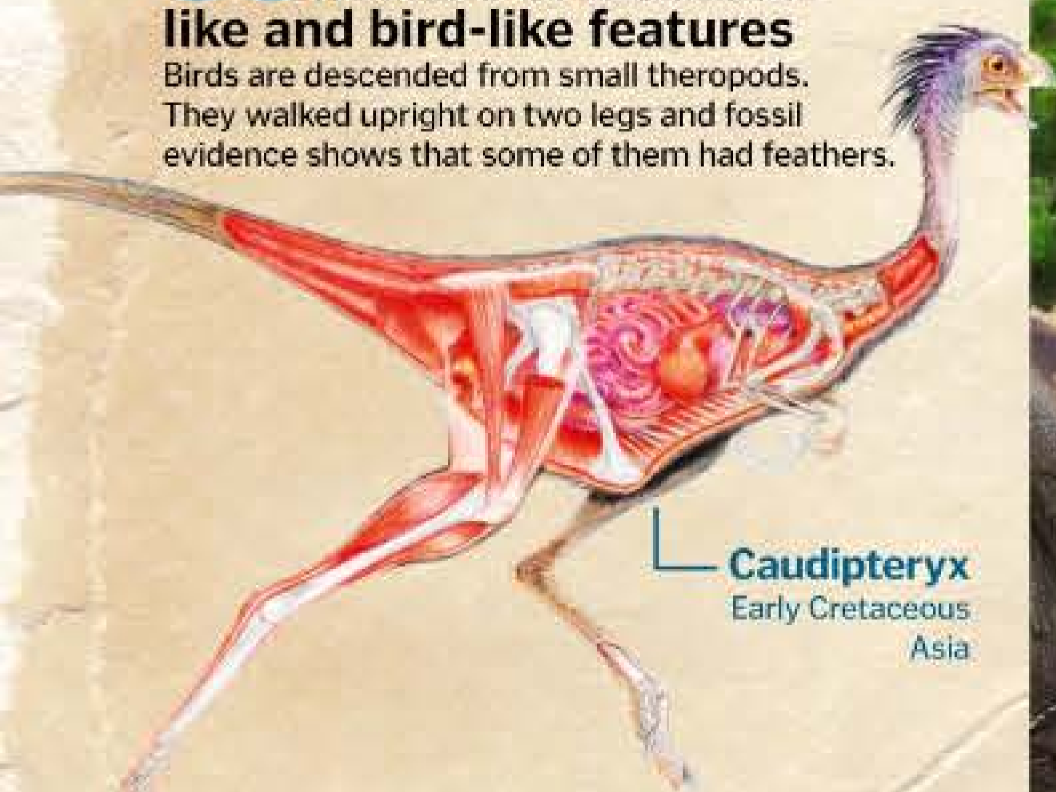
Crocodiles and lizards walk with their legs out to the sides, but dinosaurs have their legs underneath their bodies, allowing them to run faster.

65 Some dinosaurs swallowed rocks

Many plant-eating dinosaurs have been found with groups of rounded stones inside their ribcages, indicating they swallowed stones to aid digestion, like modern birds.

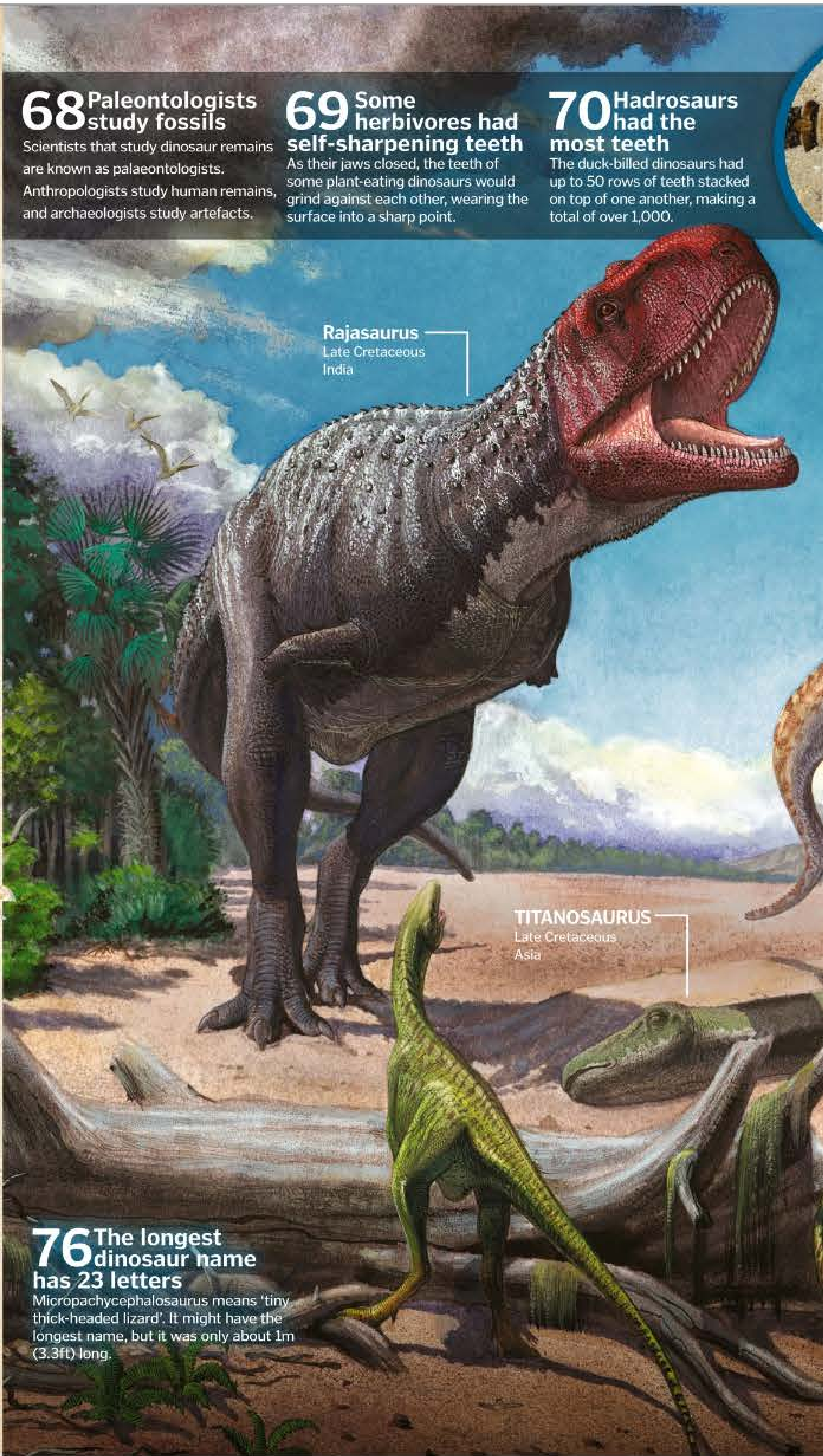
66 Some dinosaurs had a mixture of dinosaur-like and bird-like features

Birds are descended from small theropods. They walked upright on two legs and fossil evidence shows that some of them had feathers.



67 Dinosaurs lived in a changing world

Around 250 million years ago, all of Earth's landmasses were joined in a supercontinent known as Pangaea. During the reign of the dinosaurs, this landmass split apart, first into two and then into the seven continents we see today.



68 Paleontologists study fossils

Scientists that study dinosaur remains are known as palaeontologists. Anthropologists study human remains, and archaeologists study artefacts.

69 Some herbivores had self-sharpening teeth

As their jaws closed, the teeth of some plant-eating dinosaurs would grind against each other, wearing the surface into a sharp point.

70 Hadrosaurs had the most teeth

The duck-billed dinosaurs had up to 50 rows of teeth stacked on top of one another, making a total of over 1,000.

76 The longest dinosaur name has 23 letters

Micropachycephalosaurus means 'tiny thick-headed lizard'. It might have the longest name, but it was only about 1m (3.3ft) long.

71 Dinosaurs had giant fleas

Fossilised remains reveal that dinosaurs in the Cretaceous and Jurassic were hosts to giant flea-like insects measuring ten times the size of modern fleas.

72 Ornithopods walked on two legs

Dinosaurs like Iguanodon and the duck-billed Hadrosaurs walked upright on two legs, and lived in herds like modern-day antelope.

73 One dinosaur is named after the Harry Potter books

Dracorex hogwartsia ("dragon king of Hogwarts") was a pachycephalosaur with a large bulge on its forehead and a dragon-like spiked frill.

74 Dinosaurs survived for 165 million years

People often think of the dinosaurs as being evolutionary failures, but they survived for a staggering 165 million years, far more impressive than the 200,000 years managed so far by humans.

FACT 75

35m

Argentinosaurus was longer than a blue whale

77 Many dinosaurs had hollow bones

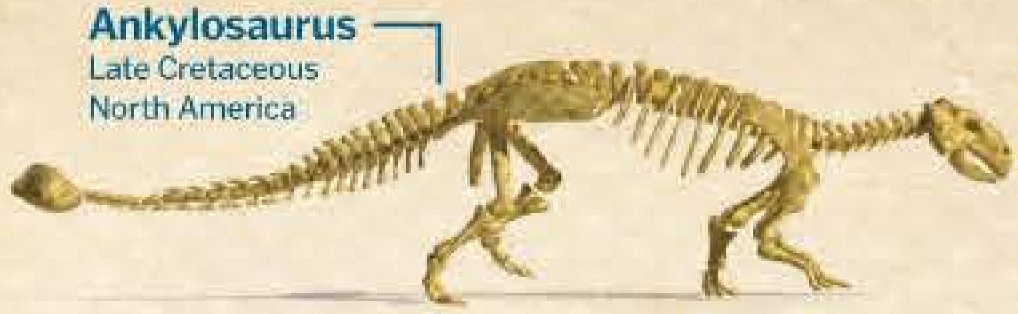
Birds have hollow bones, which helps to keep their weight down for flight and enables a unique way of breathing – sauropods and theropods had hollow bones too.

78 Lots of dinosaurs were smaller than a human

Diplodocus, Triceratops, T-rex and Stegosaurus were all enormous, but many of the two-legged raptors and some of the herbivores were smaller than we are.

Hunting dinosaurs

Fossils have be found on every continent on Earth...

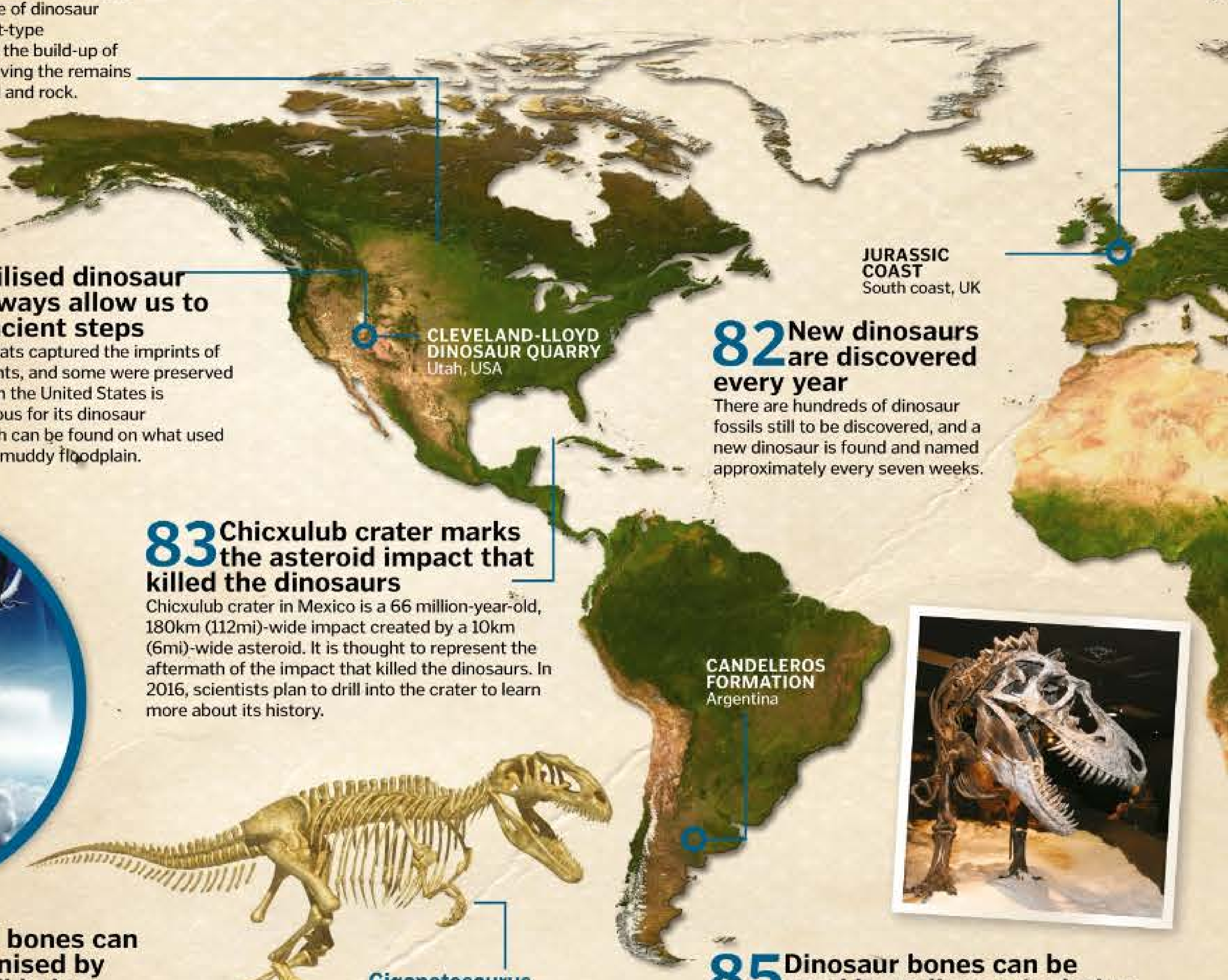


79 North America has excavated the most dinosaur fossils

North America, Argentina and China have more than their fair share of dinosaur fossils. Areas with desert-type environments prevented the build-up of thick layers of plants, leaving the remains easier to find under sand and rock.

80 The first dinosaur fossil was found in England

The first dinosaur to be scientifically documented was Megalosaurus, formally named by William Buckland in 1824. The fossils were found in a quarry in Oxford.



81 Fossilised dinosaur highways allow us to retrace ancient steps

Enormous mudflats captured the imprints of dinosaur footprints, and some were preserved as fossils. Utah in the United States is particularly famous for its dinosaur trackways, which can be found on what used to be an ancient muddy floodplain.

82 New dinosaurs are discovered every year

There are hundreds of dinosaur fossils still to be discovered, and a new dinosaur is found and named approximately every seven weeks.

83 Chicxulub crater marks the asteroid impact that killed the dinosaurs

Chicxulub crater in Mexico is a 66 million-year-old, 180km (112mi)-wide impact created by a 10km (6mi)-wide asteroid. It is thought to represent the aftermath of the impact that killed the dinosaurs. In 2016, scientists plan to drill into the crater to learn more about its history.

84 Dinosaur bones can be recognised by distinctive skull holes

All dinosaurs have the same basic skull, with two holes for jaw muscles behind the eye and an air socket between the eyes and nose.

85 Dinosaur bones can be aged by radiometric dating

Carbon dating doesn't work on dinosaur bones, so scientists estimate the age of fossils by measuring radioactive isotopes in the surrounding rocks.

95 Dinosaurs weren't the first reptiles to rule the Earth

Around 300 million years ago amphibians dominated Earth, but as it got warmer, reptiles took over. There were pelycosaurs, mammal-like reptiles called therapsids, and archosaurs, from which dinosaurs, crocodiles and pterosaurs evolved.

96 Dinosaurs lived for up to 300 years

Paleontologists estimate the large dinosaurs had life spans ranging from 75 to 300 years. These estimates were made based on information we have on cold-blooded animals – warm-blooded creatures have shorter lives.

97 Troodons were probably the cleverest dinosaurs

Troodons lived around 77 million years ago and were about two metres (6.6 feet) long. They were carnivores, walked on two legs and had relatively large brains. They are also thought to be related to modern birds.

98 Amber insects don't contain dinosaur DNA

Jurassic Park is based on the idea that you could extract dinosaur DNA from blood preserved inside the bodies of mosquitoes encased in amber. Despite several attempts to recover DNA, it seems it doesn't actually survive inside the amber.

DID YOU KNOW? Smilodon, the sabre-toothed cat, first appeared over 62 million years after the extinction of the dinosaurs

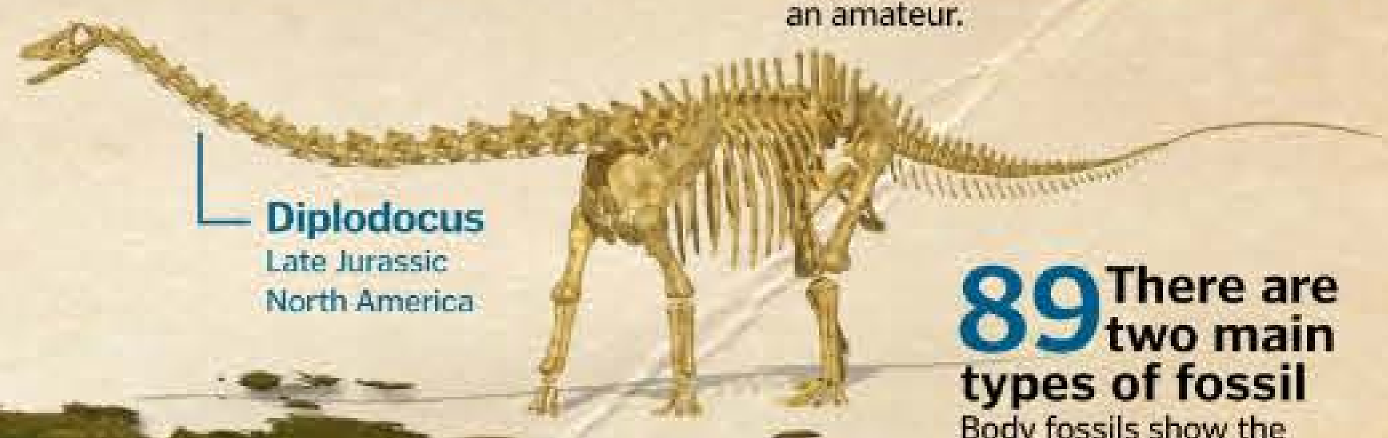
Megalosaurus
Mid Jurassic
Europe

86 More than 100 different dinosaurs lived in Britain

Britain used to form a land bridge that connected Europe to North America, and has been described as a dinosaur paradise. It was home to over 100 different species, including armoured ankylosaurs, giant sauropods and three different types of fearsome tyrannosaur.

87 There's no actual bone in a dinosaur fossil

When dinosaurs died, their bones were covered in sediment that was compressed and turned to rock. Over time, the bone itself dissolved away, leaving a bone-shaped hole in the rock, which then filled with minerals, forming a cast.



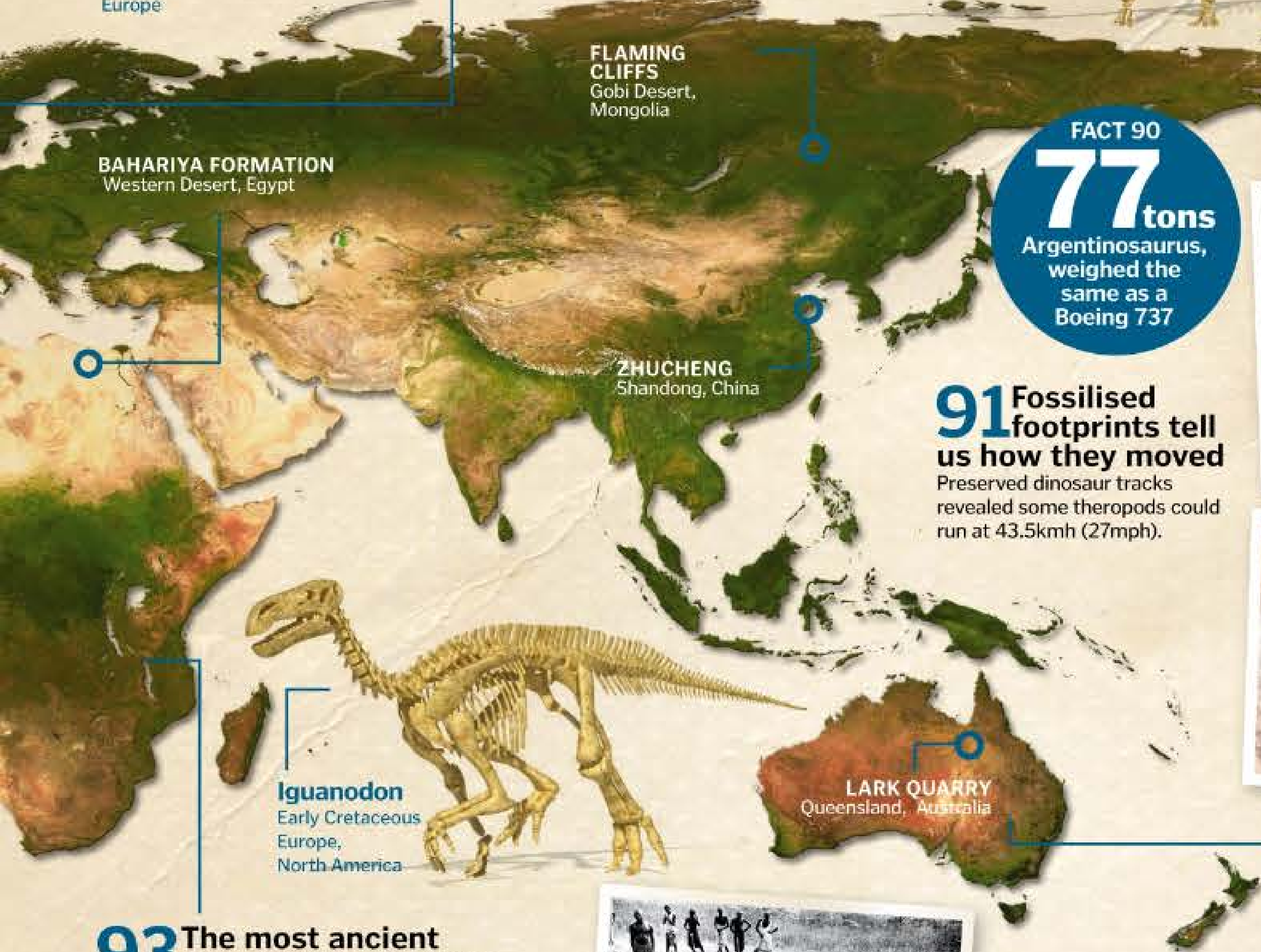
Diplodocus
Late Jurassic
North America

88 Most dinosaur fossils were found by amateurs

There are many more amateur fossil hunters than professionals, and they can cover much more ground. The largest T-rex fossil ever was found by an amateur.

89 There are two main types of fossil

Body fossils show the actual shape of dinosaur remains, while trace fossils show evidence of their lives, like footprints and nests.



FACT 90

77 tons

Argentinosaurus, weighed the same as a Boeing 737

91 Fossilised footprints tell us how they moved

Preserved dinosaur tracks revealed some theropods could run at 43.5kmh (27mph).

Iguanodon
Early Cretaceous
Europe,
North America

92 Dinosaurs ran along riverbeds

Fossilised dinosaur tracks found in Australia reveal a superhighway where two-legged dinosaurs travelled on tiptoe through a fast-moving river.

93 The most ancient dinosaur fossils were found in Tanzania

One of the earliest-ever dinosaur fossils found is a 243-million-year-old dog-sized dinosaur called Nyasasaurus parringtoni. Bones from two different individuals were excavated in the 1930s, but weren't properly studied until 2012.

94 Dinosaur fossils are found on all seven continents

Dinosaur fossils have been found in the very northern parts of Canada, right down to the frozen wastes of Antarctica.

Utahraptor
Early Cretaceous
North America

99 Raptors had feathers

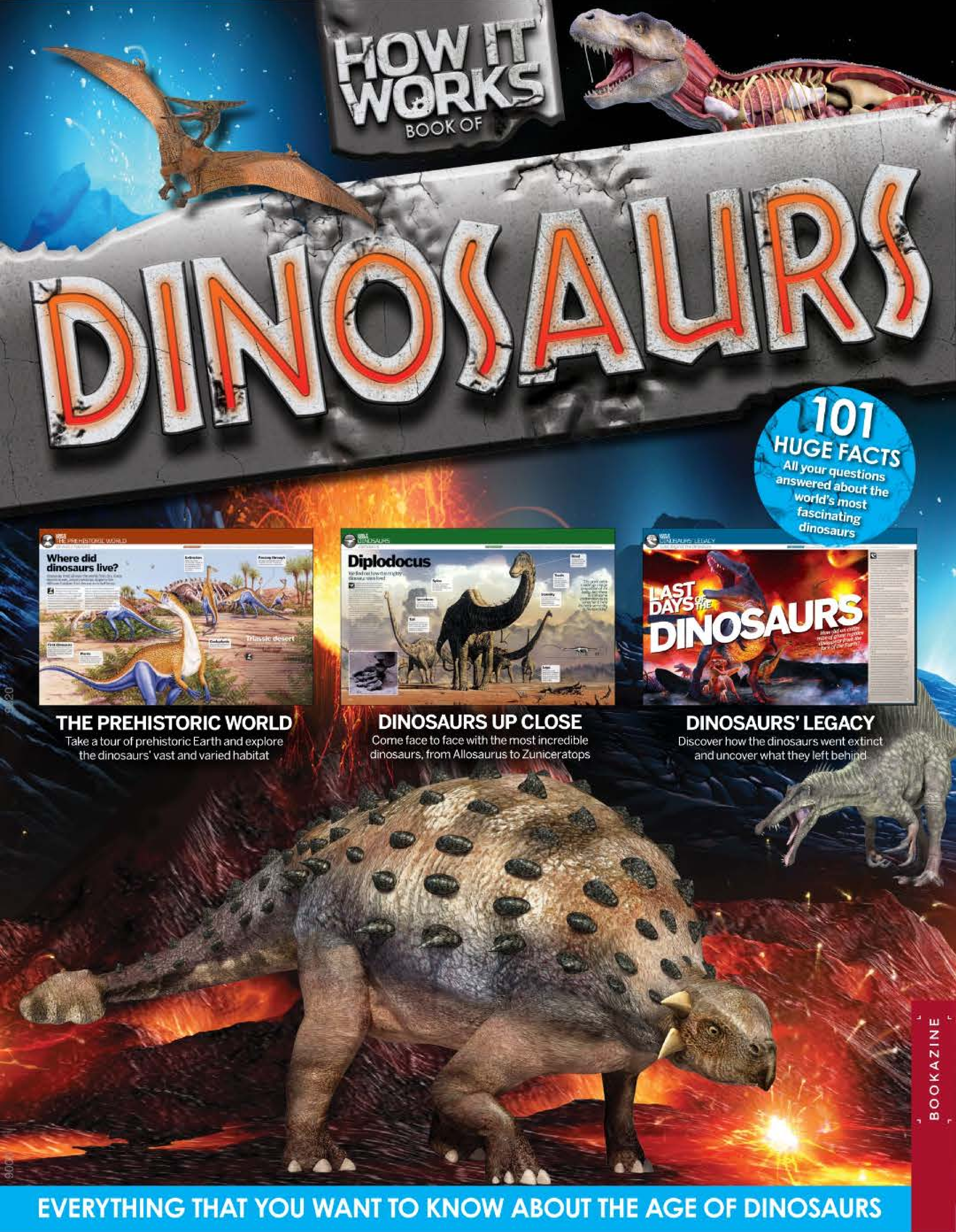
Of all the dinosaurs, the most feathery were the theropods. Velociraptors were covered in a layer of feathers, and so too was T-rex. Many other dinosaurs had spiny quills or feathery stubs.

100 Mammals used to eat dinosaurs

Repenomamus robustus was a 1m (3.3ft)-long mammal that lived approximately 125 million years ago. One specimen was found with dinosaur remains inside it.

101 Brontosaurus might have been a real dinosaur after all

Fossils were mixed up and the head of a Camarasaurus was placed on the body of an Apatosaurus. However, in 2015, a new study of the bones revealed that Brontosaurus has a longer and thinner neck than Apatosaurus and thus might be a distinct species after all.



HOW IT WORKS
BOOK OF
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101 HUGE FACTS
All your questions answered about the world's most fascinating dinosaurs
Where did dinosaurs live?
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Diplodocus
LAST DAYS OF THE DINOSAURS
THE PREHISTORIC WORLD
Take a tour of prehistoric Earth and explore the dinosaurs' vast and varied habitat
DINOSAURS UP CLOSE
Come face to face with the most incredible dinosaurs, from Allosaurus to Zuniceratops
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Discover how the dinosaurs went extinct and uncover what they left behind
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